5. PREVENTING FUTURE BERYLLIUM DISPOSAL IN THE SUBSURFACE DISPOSAL AREA

This section discusses the plan to prevent the future disposal of the ATR, ETR, and MTR beryllium reflector waste in the SDA active pit.

5.1 Advanced Test Reactor Beryllium Waste Future Generation and Disposal

The ATR is an operating test reactor. The test program planning assumption for the ATR projects that the reactor will operate (at historical power levels) through the year 2050. Historically, beryllium reflectors are changed out on an 8- to 10-year interval. Four CICs have been completed to date. Of the 32 blocks and 48 OSCCs generated to date, 20 blocks and nine OSCCs have been disposed of. (Note: Core 2 reused the OSCCs from Core 1.) The next CIC (replacing Core 5 with Core 6) is planned for 2004. Using an average 9-year changeout interval, starting after the 2004 CIC, approximately five more CICs will be completed through 2050. Including the 2004 CIC and five more CICs, the authors project that 48 more beryllium blocks and 96 OSCCs will be generated. Twelve blocks and 39 OSCCs generated from previous CICs are currently in the ATR storage canal. Total beryllium waste requiring disposal in the future is estimated at 60 blocks and 135 OSCCs. Also, beryllium reflector experiment test plug-hole fillers that are used from core to core will require disposal at facility closure. The number of experiment hole fillers and their masses are not known at this time.

New characterization information for the beryllium blocks and OSCCs has changed the waste stream classification of the ATR beryllium waste from LLW to TRU. If the uranium chemical impurity in the future-procured beryllium reflectors remains similar to beryllium used in the past, all future-irradiated ATR beryllium will be classified as TRU. This waste stream designation will prohibit future beryllium disposal in the SDA as LLW.

In addition, beryllium from the ATR Critical (ATRC) facility will have to be characterized and eventually disposed of at some future time. The ATRC is a very low-power replica of the ATR core. This facility is currently operational and supports the ATR operation by determining in advance the nuclear characteristics of experiments programmed for irradiation in the ATR. The ATRC beryllium reflector is a full-scale replica of the ATR core and includes OSCCs and beryllium test plughole fillers. However, because of the very low power history for the ATRC, the beryllium waste from this reactor, at decommissioning, possibly will be suitable for LLW disposal. The ATRC is assumed to be operational for the same period (2050) as the ATR. The original ATRC beryllium reflector is still in the reactor. The reflector is assumed to remain in the reactor during the future ATR operational period. Sufficient flux exposure of the beryllium to cause the beryllium reflector to be classified as TRU is highly unlikely because of the low power levels and infrequent periods at which the ATRC operates.

An option addressed in "Radioactive Waste Management" (DOE O 435.1, 2001) allows special performance assessment-based disposal decisions to be made when technical justification exists. Final disposal approval is required from the U.S. Secretary of Energy with concurrence from the U.S. Environmental Protection Agency (EPA) administrator. The decision process evaluates the technical bases of a TRU and determines whether the waste requires the degree of isolation provided for TRU. If the evaluation determines that a waste does not require the degree of isolation required for TRU, then it can be exempted from the TRU classification and reclassified as LLW. Though beryllium waste may not need the degree of isolation generally required for typical TRU, pursuing an exemption under this provision will be difficult because no precedent for seeking such an exemption or experience with the process itself has been reported. Therefore, the outcome of an attempt to receive an exemption is highly questionable.

Because the current and future ATR beryllium reflector waste is classified as TRU, it does not meet LLW disposal criteria. Disposal of the ATR and ATRC beryllium reflector as LLW in the SDA LLW disposal facility is not anticipated because the SDA LLW disposal facility will be volume-filled by 2020 or administratively closed in 2009, a full 30 years before the anticipated decommissioning of the ATR and ATRC.

5.2 Materials Test Reactor Beryllium Waste Future Generation and Disposal

The MTR reactor is deactivated; however, the second beryllium reflector remains in the reactor. Beryllium waste generation for the MTR will be a concern for a future deactivation, decontamination, and decommissioning (D&D&D) project. The D&D&D of the MTR is scheduled after 2012. An MTR characterization report (Rolfe and Wills 1984) indicated that the initial beryllium core was removed in 1969 and a new one was installed. The beryllium core changeout occurred near the end of the operational life of the facility. Therefore, the remaining beryllium core was not exposed to large amounts of neutron flux. The characterization report addressed the beryllium reflector characterization, but not sufficiently to allow a TRU stream determination to be made. Evaluating the remaining MTR beryllium reflector is beyond the scope of this report. However, because of the low neutron exposure, it may not be TRU. Further characterization will be required to develop a final waste stream determination at the time of decommissioning. Disposal of the MTR beryllium reflector as LLW in the SDA LLW disposal facility is not anticipated because the SDA LLW disposal facility will be volume-filled by 2020 or administratively closed in 2009.

5.3 Engineering Test Reactor Beryllium Waste Future Generation and Disposal

The ETR reactor is deactivated. Beryllium waste generation in the ETR will be a concern for a future D&D&D project. The D&D&D of the ETR is scheduled after 2012. An ETR characterization report (Kaiser et al. 1982, p. 35) indicated that the initial beryllium core was removed in 1970 and a new beryllium core was installed. The new beryllium reflector remained in the operating reactor through 1980 when it was shut down. During this operational period, the new beryllium reflector experienced significantly low neutron fluence, which may not have been sufficient to cause the reflector to become TRU. The ETR characterization report addressed beryllium reflector characterization, but not sufficiently to allow a TRU stream determination to be made. Evaluating the remaining ETR beryllium reflector characterization is beyond the scope of this report. However, because of the low neutron exposure, the beryllium reflector may be LLW. Further characterization will be required to develop a final waste stream determination at the time of the ETR decommissioning. Disposal of the ETR beryllium reflector as LLW in the SDA LLW disposal facility is not anticipated because the SDA LLW disposal facility will be volume-filled by 2020 or administratively closed in 2009. The ETR could undergo D&D&D in 2012, which is before the 2020 SDA late closing date but after the administrative closure date. The assumption for this report is that the ETR beryllium will not be disposed of in the SDA. Though the beryllium reflector may remain classified as remote-handled LLW in the future, it will likely not be disposed of at the INEEL because INEEL disposal facilities are scheduled to close within 5 years according to the 2012 Plan for the INEEL (DOE-ID 2002b). The ETRC, a low-power companion reactor to the ETR, supported the ETR operation by determining in advance the nuclear characteristics of experiments programmed for irradiation in the ETR. The building that housed the reactor has had all the radioactive materials removed. The beryllium reflector is assumed to be among these radioactive materials and to have been disposed of previously in the SDA. No future beryllium reflector waste will be generated from the ETRC.

5.4 Future Advanced Test Reactor Beryllium Procurements

A future beryllium procurement possibility exists that may benefit beryllium disposal. Revising the ATR beryllium procurement specification may be technically and economically feasible to reduce allowable chemical impurity levels in future beryllium material for those elements that complicate waste disposal.

This option would not be applicable to the beryllium waste currently stored in the canal, to beryllium waste generated at the 2004 CIC, or to beryllium waste removed from the reactor at the 2012 CIC. The beryllium reflectors to be installed at the 2004 CIC have been procured and are in storage at TRA. The new beryllium reflectors have measured chemical impurities that indicate they will be at higher activity levels for TRU and C-14 when removed at the 2012 CIC than the stored beryllium reflectors. However, the ATR beryllium reflector procurement is a long-lead item. The next beryllium procurement to provide reflectors for the 2012 CIC will start some time near 2007.

Because of the low-power nature of the ATRC, the existing beryllium reflector is assumed to not require replacement during the operational time period (2050) of the ATR reactor.

6. MONTE CARLO N-PARTICLE CALCULATION CHARACTERIZATION

This section describes the MCNP4B (LANL 1997) calculation techniques and tools, which are employed to accurately predict activation product concentrations or radionuclide inventories for an irradiated beryllium block.

6.1 Calculation Characterization Requirement

Characterization of the beryllium blocks relies on both calculation and measurement techniques. Both techniques play a critical role in the characterization process and together build confidence in the final characterization conclusions. The measurement or assay samples taken from the blocks remaining in the ATR storage canal provide valuable information, but typically are small samples taken from a few specific locations around the block and ultimately provide only a limited number of radionuclide concentrations. However, these measurement samples do provide direct characterization information and, perhaps more importantly, validate the corresponding calculated radionuclides at these specific locations. These in turn provide some level of validation of the computer codes, computer models, calculation methodology, and the calculated block radionuclide inventories. The calculated radionuclide inventory is then relied on to provide full characterization information for each whole beryllium block.

The authors have attempted to simulate through calculation the irradiation environment to which the beryllium blocks were exposed during their residency in the ATR core. Sophisticated computer codes, relatively large computer models of the reactors, and substantial input data are required for such simulation. The computer codes, methodology, and input data are discussed below in some detail. The primary strength of the calculation characterization technique is its ability to provide activation product concentrations anywhere in the beryllium block for any radionuclide of interest and at any point in time during or following the irradiation.

This powerful calculation technique provides the capability to estimate an average radionuclide inventory for an entire beryllium block or OSCC, or a local radionuclide inventory of any selected sub-volume of either component. The ability to calculate a local radionuclide inventory allows for direct comparison of radionuclide concentrations taken from small assay samples. Comparisons of calculated versus measured radionuclide concentrations provide confidence in the total calculated radionuclide inventory, and the total calculated radionuclide inventory is relied on heavily for the average beryllium block characterization.

Measurement samples taken at Sites 1 and 2 on the 010R beryllium block (see Figure 6-1) showed large differences in TRU concentrations. The differences were attributed to the large variations in neutron flux and neutron energy spectra between the two sample locations. Clearly, somewhere between the front face of the beryllium block (Site 2) and the peripheral edge of the block top surface (Site 1), the TRU concentration reached a maximum because the calculated average block TRU concentration was higher than at either Site 1 or Site 2. This conclusion led to the development of the segmented beryllium block model as part of the calculation characterization effort to establish a three-dimensional TRU distribution within the 010R beryllium block. The model provided some very interesting results, which are discussed below, and helped to identify those block regions of maximum TRU concentration.

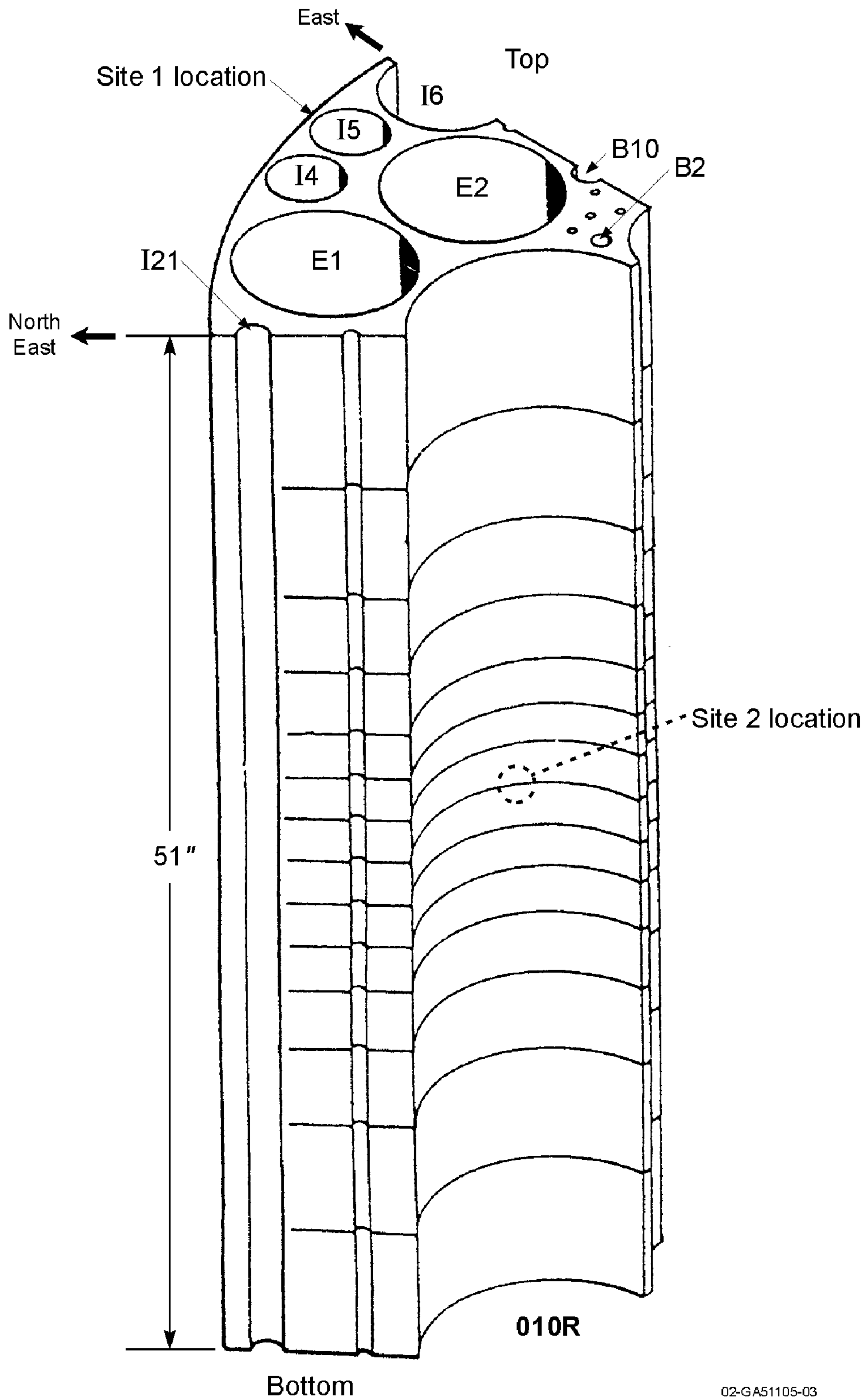


Figure 6-1. A schematic of Advanced Test Reactor reflector Block 010R showing the locations of sample Sites 1 and 2.

6.2 Computer Code Simulations

The three computer codes were used to estimate radionuclide inventories:

- Monte Carlo N-Particle Version 4B (LANL 1997)
- Oak Ridge Isotope GENeration and Depletion Code Version 2 (Croff 1980)
- MCNP4B-ORIGEN2 Coupled Utility Program Code (MOCUP) (Babcock et al. 1994).

These computer codes were used to develop the necessary nuclear reaction cross sections and irradiation-flux levels as a function of position in the beryllium and to perform the activation analyses.

The MCNP4B computer code is a general purpose, continuous energy, generalized geometry, and coupled neutron-photon-electron Monte Carlo transport code. This code performs the neutron transport calculation to determine the flux and reaction rates in the geometry model cells and the desired neutron cross sections. A wide variety of nuclide cross-sections and reactions are available from the Evaluated Nuclear Data File-5 and -6.

The ORIGEN2 code (Croff 1980) was used for calculating the buildup, destruction, and decay of stable and radioactive isotopes. Coupled ordinary differential equations describing the complex burnup and decay mechanisms between the nuclides are solved using the matrix exponential method. Several standard neutron cross-section, decay, and production data libraries are available with the code for a narrow range of applications. A special feature of the ORIGEN2 code is a user option to modify the standard cross-section libraries with user-supplied cross sections, thereby allowing a burnup calculation to be reactor-specific. ORIGEN2 performs the burnup calculation with effective one-group cross sections with depletion controlled either by power or irradiation flux level.

The MOCUP computer code (Babcock et al. 1994) is a utility code composed of a system of external processors that link input and output files from the MCNP4B and ORIGEN2 codes. For characterization analyses, the MOCUP code was used only to transcribe neutron fluxes and nuclear reaction rates into one-group neutron cross sections for use in ORIGEN2. The MOCUP code is composed of three processing modules, namely, mcnpPRO, origenPRO, and compPRO. Each module performs specific, sequential tasks during each time step or burnup iteration.

6.3 Calculation Methodology

The calculation methodology uses mcnpPRO, origenPRO, and compPRO computer codes in a serial process. The MCNP4B code performs the neutronic transport calculation to determine the cell fluxes and reaction rates. The MOCUP code reads the MCNP4B output and arithmetically manipulates the data into one-group cross sections for input into the ORIGEN2 code. To obtain the radionuclide concentrations ORIGEN2 is then used to perform the time-dependent, nuclide-coupled depletion or activation analysis calculation. The ORIGEN2 calculation requires other input data in addition to the neutron cross-sections, as discussed below.

To perform the MCNP4B neutronic calculations, a geometric model of the ATR core is required. A full-core, fully explicit, three-dimensional geometry and material model of the entire ATR core is used to account for core axial and radial asymmetries. This model contains the major ATR core features including the 40 driver fuel elements, nine flux trap facilities, safety rods, neck shim housing, shim control rods, 16 OSCCs, and the eight beryllium reflector blocks. The beryllium reflector blocks are modeled individually and can be subdivided further as was done for Site 1, Site 2, and the segmented three-dimensional model, to obtain cell-specific and location-specific neutron cross sections. A cross-sectional view of the MCNP4B ATR core model is shown in Figure 6-2. Each colored section of Figure 6-2 represents a different region of the computer model. For example, the purple region represents the 40 curved fuel elements, the light-yellow cylinders are the beryllium metal contained within the 16 OSCCs (and the adjacent black sections represent the hafnium plates), and the light-green area models the 8 ATR beryllium blocks.

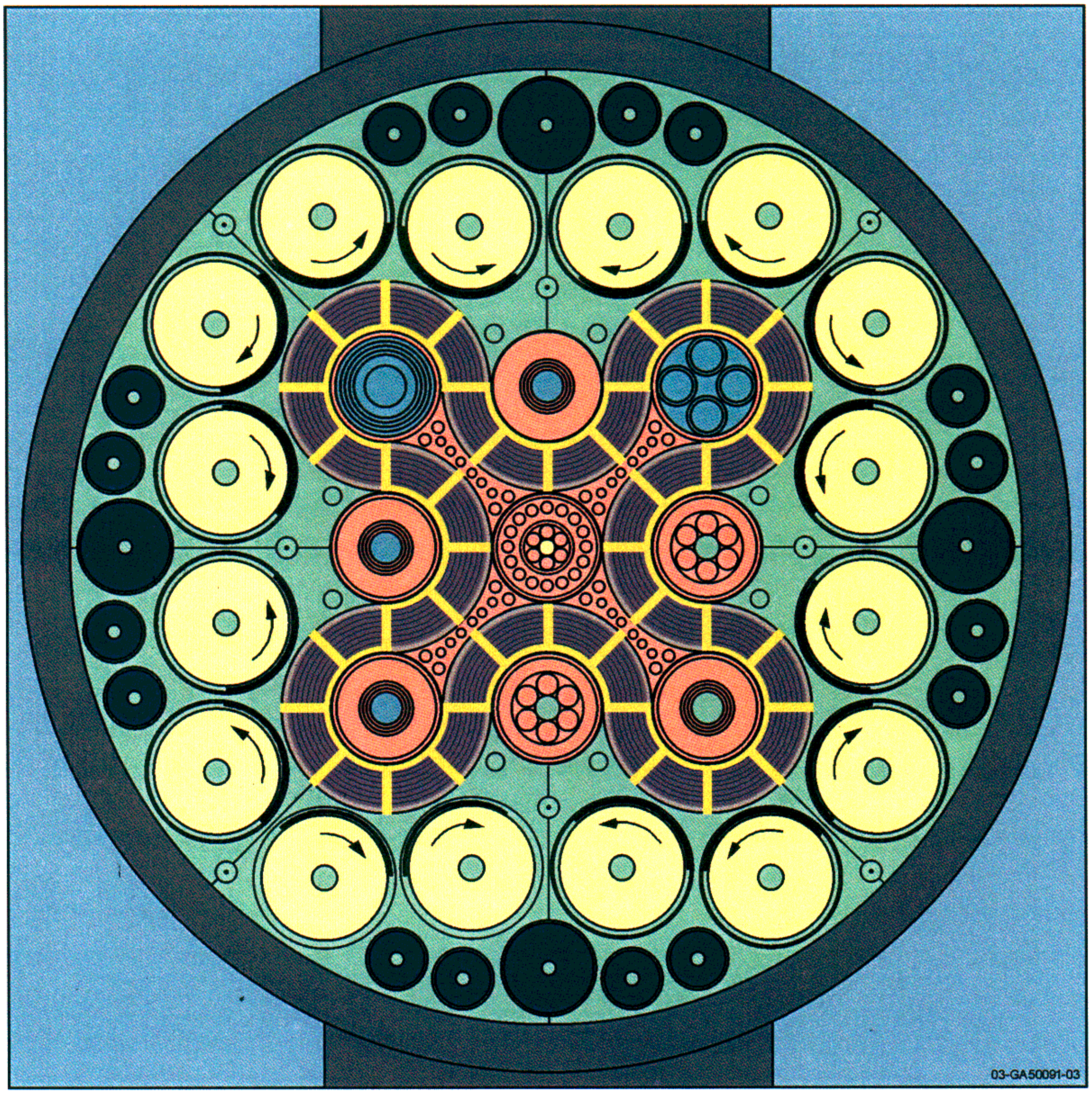


Figure 6-2. Cross-sectional view of the Monte Carlo N-Particle Version 4B Advanced Test Reactor full core model.

The nuclear reaction rates were calculated by MCNP4B for a variety of actinides and selected precursor activation products. Reaction rates were determined for 37 actinides, including 12 of the 13 important actinides that form the basis of the TRU definition, plus 24 selected activation product and precursor nuclides that also are included and given in the Table 6-1.

For each of the 37 actinide nuclides, four nuclear reaction rates were calculated, namely, (n,f), (n, γ), (n,2n), and (n,3n). For the activation product nuclides, four nuclear reaction rates are calculated, namely, (n,γ), (n,2n), (n,α), and (n,p).

The ORIGEN2 code performed the activation analysis. In addition, to the location-specific neutron cross sections, the irradiation flux and the beryllium block mass constituents were required as input data. The beryllium block irradiation flux is calculated by MCNP4B and normalized, based on the ATR lobe exposures. Table 6-2 below gives the ATR core total exposures for Cores 1 through 4, along with the corresponding operational dates and durations (Appendices Y, Z).[d]

Table 6-1. List of actinide and activation product nuclides for which nuclear reaction rates are calculated by the Monte Carlo N-Particle Version 4B computer code.

Actinides	Activation Products
Th-232, Th-233	Li-6
Pa-233	Be-9
U-233, U-234, U-235, U-236, U-237, U-238, U-239, U-240	C-12, C-13
Np-235, Np-236, Np-237, Np-238	N-14
Pu-237, Pu-238, Pu-239, Pu-240, Pu-241, Pu-242, Pu-243	O-17
Am-241, Am-242m, Am-243	Co-59, Co-60, Co-60m
Cm-242, Cm-243, Cm-244, Cm-245, Cm-246, Cm-247, Cm-248,	Ni-58, Ni-59, Ni-60, Ni-61, Ni-62, Ni-63, Ni-64
Bk-249	Cu-63
Cf-249, Cf-250, Cf-251, Cf-252	Zn-66
	Nb-93, Nb-94
	Mo-94, Mo-98, Mo-99
	Tc-99

Table 6-2. Advanced Test Reactor core data and total core exposures.

Advanced Test Reactor Core	Time Period	Duration (days)	Start and End Cycles	Approximate Number of Power Cycles	Total Core Exposure (MWd)
1	02/01/68 to 09/09/72	1,682	Initial Critical to 14A	45	141,240
2	02/05/73 to 04/11/77	1,526	15A to 34C1	64	153,734
3	08/09/77 to 02/02/86	3,098	35A7 to 72A1	120	305,241
4	05/18/86 to 02/27/94	2,843	73A9 to 102B1	90	267,247

d. Schnitzler, B. G., Interdepartmental Correspondence to J. A. Logan, March 23, 1998, "Estimated C-14 Production in the Advanced Test Reactor Coolant," Idaho National Engineering and Environmental Laboratory, Idaho Falls, Idaho.

As an example, the 010R beryllium reflector block resided in the northeast (NE) lobe of Core 3. Table 6-3 gives four Core 3 lobe exposures. The NE lobe exposure was used to normalize the 010R block irradiation fluxes.

The beryllium block mass constituents (beryllium mass plus the assortment of impurity masses) also are important pieces of input data for the ORIGEN2 activation calculation. The beryllium constituent masses are based on reflector material and chemical impurity information previously provided. The accuracy of the beginning of life chemical impurities plays an important role in the quest to obtain an accurate activation analysis and radionuclide inventory prediction.

The three major input data, neutron cross sections, irradiation flux, and beryllium masses, are required for each activation analysis.

Table 6-3. Core 3 lobe exposure data.

Lobe	Irradiation Time (days)	Lobe Exposure (MWd)
NE	3,098	47,259
SE	3,098	72,984
SW	3,098	60,200
NW	3,098	53,920

NE = northeast NW = northwest SE = southeast SW = southwest

6.4 Five Activation Analyses

Five separate activation analyses were performed to estimate the neutron-induced radioactivity in the 010R beryllium block. These five analyses focused on (1) the whole beryllium block, (2) Site 1, (3) Site 2, (4) an OSCC, and (5) a segmented beryllium block. All five analyses relied on the same basic calculation methodology described above to develop location-specific neutron cross sections and irradiation fluxes. Location-specific cross sections and fluxes also were critical for accurate radionuclide activity estimates, as was evident in the early comparisons of calculated versus measured radionuclide concentrations. All other input data (e.g., exposure history and chemical impurity masses) remained the same for the five cases analyzed.

Neutron reaction cross sections were needed for all five cases as part of the activation analysis input data. These data were generated using the Monte Carlo neutron transport code, MCNP4B, and a full ATR core model with explicit three-dimensional geometric detail. The model includes the 40 driver fuel elements, eight beryllium reflector blocks, one neck shim housing, nine flux traps, and 16 outer shim control cylinders (see Figure 6-2). In particular, the 010R beryllium reflector block located in the NE reflector lobe was specially subdivided to get the needed neutron fluxes and nuclear reaction rates at specific block locations (i.e., Site 1, Site 2, and OSCC).

The MCNP4B code has the capability to calculate neutron fluxes and nuclear reaction rates in any defined cell location in the model. Using this capability, the beryllium block cells in the ATR full model were modified to calculate fluxes and reaction rates in the cell regions representing: (1) full beryllium block, (2) single low-flux location at the top periphery of the block (Site 1), (3) single high-flux location on the front face of the block at mid-plane (Site 2), (4) an OSCC, and (5) a 330-cell fully segmented block. With the cell fluxes and reaction rates, specific flux-collapsed one-group neutron cross sections could be calculated for activation product and actinide precursors. One-group reaction cross sections included fission, radioactive capture, (n,2n), (n,p), (n,α), and (n,3n) reactions.

6.5 Assumptions

The activation analysis calculations pertain only to the beryllium metal pieces of the reflector blocks. All other nonberyllium components (e.g., pads, screws, nuts, dowels, and clamps) attached to the beryllium reflector blocks were not accounted for in the calculated and reported radionuclide inventory.

All radionuclide activities were decay-corrected to July 15, 2001.

An individual beryllium block volume is 0.0447 m^3. The entire block mass is 82.7 kg, (or 81.4 kg for the beryllium metal only). The assumed beryllium density was 1.85 g/cm^3.

Constant power and flux were assumed over each ATR power phase. For the 010R block, the estimated total neutron flux was 1.342×10^{14} n/cm^2/second. The total irradiation time was 3,098 days. The decay time to July 15, 2001, was 5,642 days.

Beryllium metal uranium impurity of 30 ppm was assumed to be uniformly distributed throughout the blocks.

6.6 Segmented Model

A segmented model of the 010R beryllium block was developed to determine the detailed distribution of the TRU concentrations throughout the block volume (see Figure 6-3). Because the previously calculated average block TRU concentrations were significantly higher than both the calculated and measured TRU concentrations at Site 1 and Site 2, this meant that somewhere within the beryllium block the TRU concentrations were significantly higher than the average block value. This led the authors to questions concerning how much higher and where in the block these potentially high TRU concentrations were located. These questions could be answered only with the segmented model and the associated detailed activation analysis.

The segmented model subdivides the 010R beryllium block into five radial and six azimuthal zones or 30 r-θ segments, as shown in Figure 6-3. Note, however, that only 22 of the 30 r-θ segments actually contain a piece of the beryllium reflector block metal. Some segments contained fuel and others were for OSCC locations. In addition, the beryllium block was further subdivided into 15 axial zones with 8-cm (3-in.) segment lengths, except for the two end segments, which had 17 cm (6.5 in.) and 14 cm (5.5 in.) lengths at the top and bottom of the block, respectively. In total, the beryllium block was divided into 22×15 (or 330) individual segments.

As discussed above, the fluxes and cross sections were calculated for each of these 330 segments in the same manner as the fluxes and cross sections had been calculated for the Site 1, Site 2, OSCCs, and the entire block (average over the block). An individual activation analysis or ORIGEN2 run was performed for each of these 330 segments to obtain the radionuclide inventory of each segment. The results of which are discussed below.

6.7 Segmented Model Results

Computations were performed using the methodology and computer codes discussed above to compute the TRU-specific activities (nano-curies per gram) in each of the 330 segments. Each segment-specific activity is an average over the segment's volume. The 22 r-θ segment-specific activities are plotted in Figures 6-3 to 6-7 as a function of axial height above the bottom of the ATR active core. The location of the 22 segments corresponds to the 22 numbered segments on Figure 6-3. Figure 6-4 plots values for Segments 1 through 5, Figure 6-5 plots values for Segments 6 through 10, Figure 6-6 plots values for Segments 11 through 16, and Figure 6-7 plots values for Segments 17 through 22.

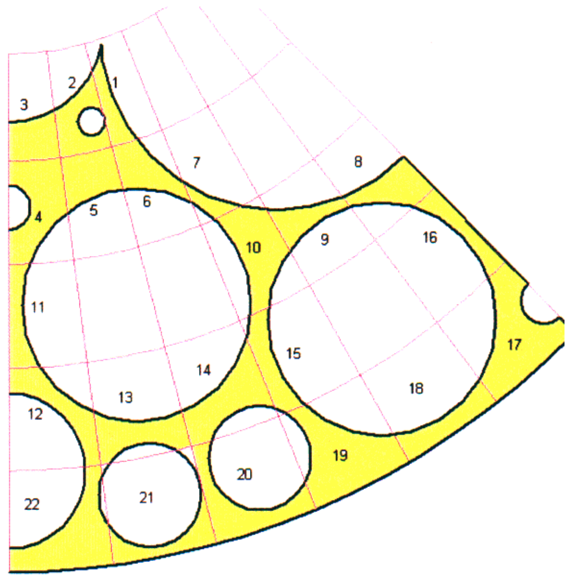


Figure 6-3. Segmentation of the Advanced Test Reactor beryllium reflector block used in the detailed calculations.

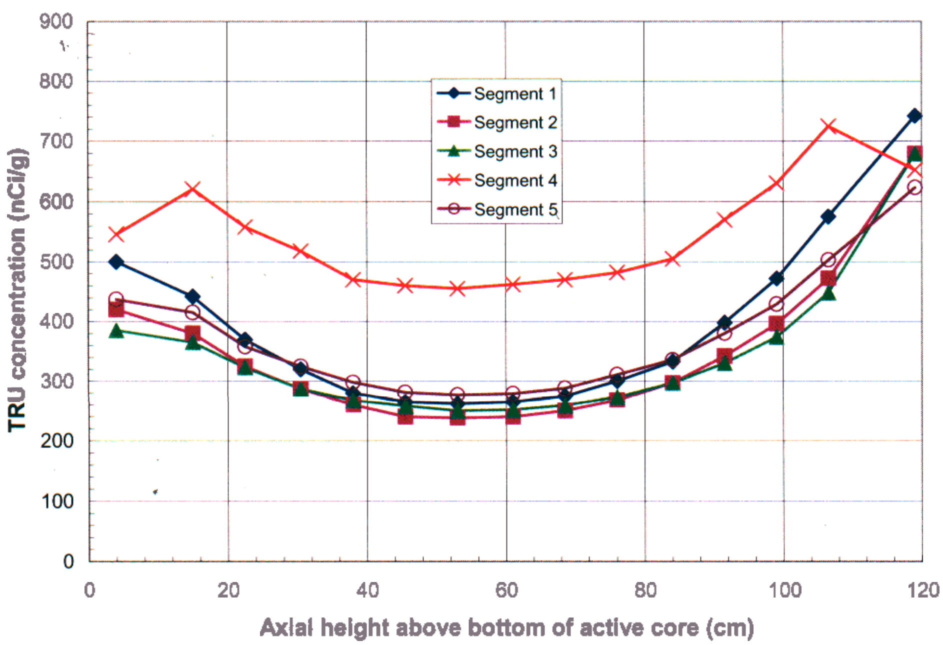


Figure 6-4. Transuranic specific activities calculated for Segments 1 through 5.

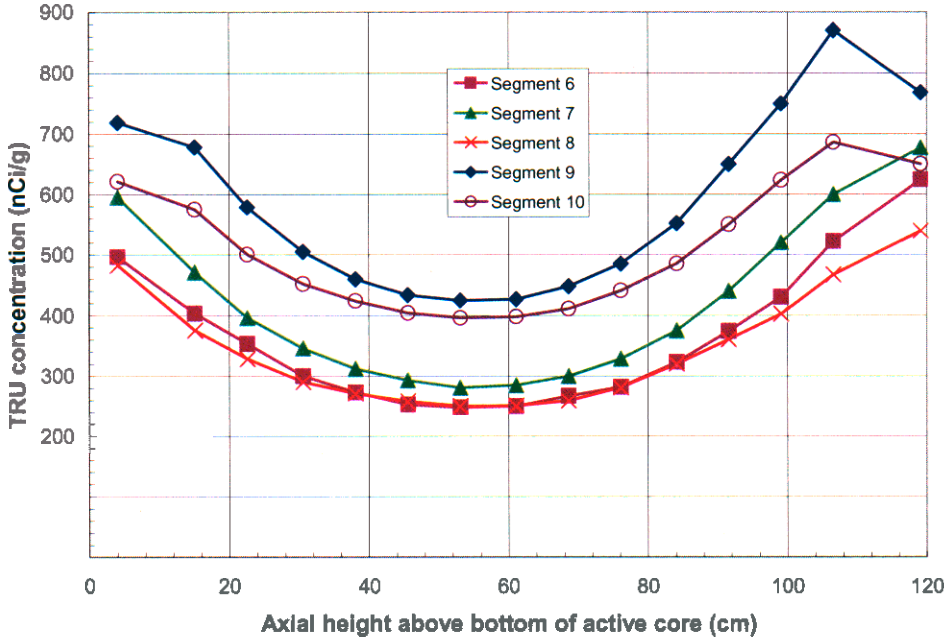


Figure 6-5. Transuranic specific activities calculated for Segments 6 through 10.

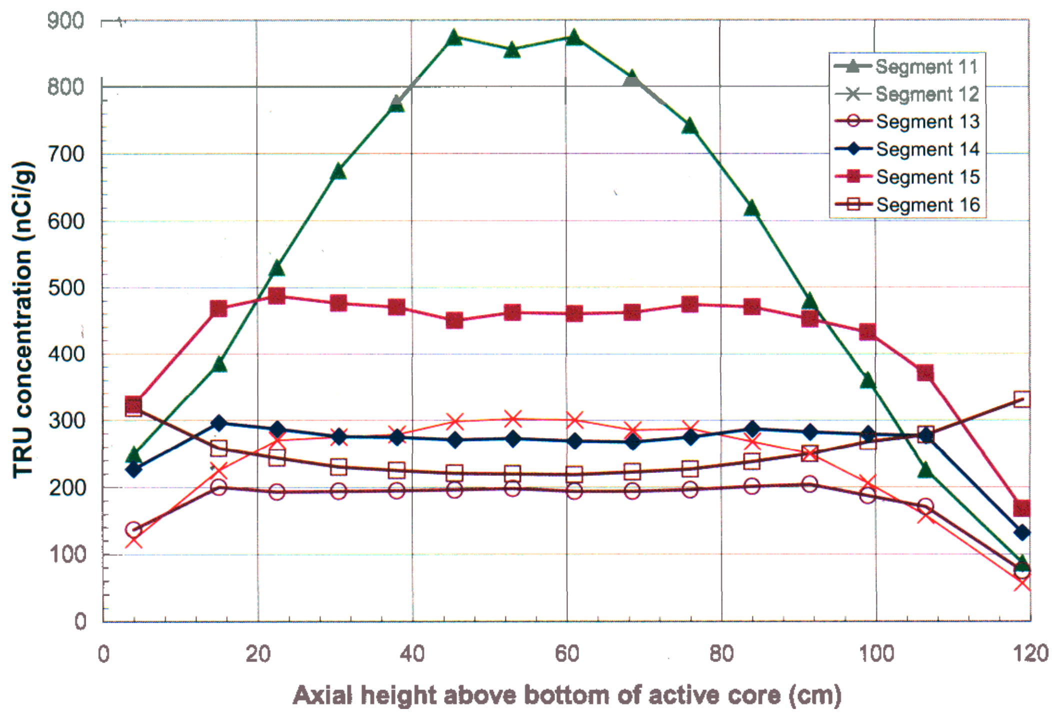


Figure 6-6. Transuranic specific activities calculated for Segments 11 through 16.

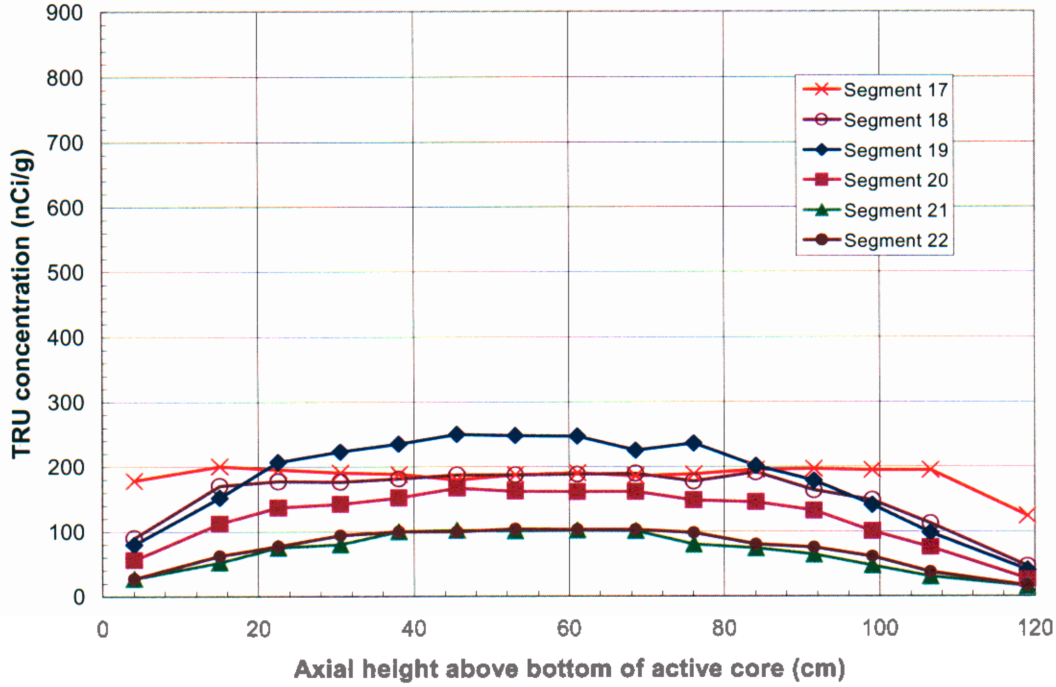


Figure 6-7. Transuranic specific activities calculated for Segments 17 through 22.

The authors surveyed Figures 6-4 through 6-7 to see which segments had the highest and lowest TRU concentrations. Segments 9 (near top of the active core) and 11 (around core midplane) appear to possess the highest TRU concentrations at approximately 890 nCi/g. Also, note that the TRU concentrations in Segments 1 through 10 exhibit a depression in the axial profile around midplane and peaking near the top and bottom of the core. The depression is believed to be the result of the higher midplane neutron fluxes in the vicinity of the driver fuel resulting in increased burnout of the uranium and TRU isotopes. Segments near the block outer periphery exhibit the lowest TRU concentrations, presumably because of the reduced neutron fluence. Apparently, an optimal neutron flux intensity and spectral content can maximize the TRU concentration in the beryllium block, as evidenced by the variation in the plots.

A comparison is provided in Table 6-4 of Pu-239 and TRU concentrations based on the segmented model calculation, a single average block, and measured assay data for Site 1, Site 2, and the block average. The single-block model uses a single calculated average flux and cross-section set. Note that all the beryllium block radionuclide inventories to date are based on this type of model. The segmented model represents a more detailed and accurate computation, but is by far more complex and time consuming, and hence limiting, in the sense that only the 010R block was analyzed.

A comparison between the segmented model and the single-block model results indicates good agreement, particularly at Sites 1 and 2 for both the Pu-239 and TRU concentrations. The Pu-239 measured value for Sites 1 and 2 are in very good agreement with both calculated values, as well. The measured TRU value at Site 2, however, is higher than the segmented model calculated values by a factor of 1.52 and 1.86 (corresponding to the two measured samples at Site 2). These factors are within a factor of two and demonstrate good agreement. Of particular interest is the fact that both the segmented model and the single-block model under-predict the measured TRU values at Site 2.

Table 6-4. Calculated and measured Pu-239 and transuranic concentrations.

Sample Locations for Block 010R	Concentration of Pu-239 (nCi/g)	Concentration of All Transuranic Isotopes (nCi/g)
Site 1		
Segmented model[a]	6.353	13.719
Single-block model	5.119	8.56
Measured	4.4	Not measured
Site 2		
Segmented model[b]	11.98	286.46
Single-block model	11.71	279.50
Measured	14.9 and 13.0	434.8 and 533.4
Block average		
Segmented model	Not measured	277.08
Single-block model	Not measured	491.23
Measured	Not measured	Not measured

a. Site 1 is contained within cell-20123 of the segmented model.
b. Site 2 is contained within cell-20807 of the segmented model.

Table 6-5 presents the fraction of the 010R block mass that exceeds different levels of specific activity. For example, approximately 97% of the beryllium block mass contains TRU concentrations in excess of 100 nCi/g and nearly 50% of the block mass is in excess of 400 nCi/g.

Other useful information derived from the segmented model includes the total TRU activity inventory, which is estimated to be 0.0277 Ci. Also, the segmented model calculations predict an overall block average TRU concentration of 277.08 nCi/g versus the 491.23 nCi/g that is computed for the single-block (ORIGEN2) model. This comparison indicates that the single-block (1-D) ORIGEN2 model may overpredict the TRU concentrations by about a factor of 1.8 (relative to the 3-D model). However, other comparisons, based on measured data and computer code results (see Section 7.6) for Sites 1 and 2, indicate the opposite effect. That is, the single-block calculations tend to underpredict the block inventories by about a factor of 1.7. Since the computer code results are only known within a factor of 2, and because the above two effects tend to cancel each other, no additional correction was attempted to better refine the single-block ORIGEN2 inventory results. In other words, the reported single-block ORIGEN2 results are considered to be best estimate.

Table 6-5. Percentage of beryllium block mass exceeding a given specific activity level.

Specific Activity Level (nCi/g)	Percentage of Beryllium Block Mass Exceeding a Given Specific Activity Level (%)
>100	96.67
>200	81.70
>300	58.85
>400	48.62
>500	30.76
>600	20.92
>700	6.67
>800	2.06
>900	0.00

7. OAK RIDGE ISOTOPE GENERATION AND DEPLETION CODE VERSION 2 INPUT MODEL DESCRIPTION

This section describes the ORIGEN2 computer model and the calculated results for the radionuclide inventory existing in the ATR, ETR, and MTR beryllium metal disposed of in the SDA.

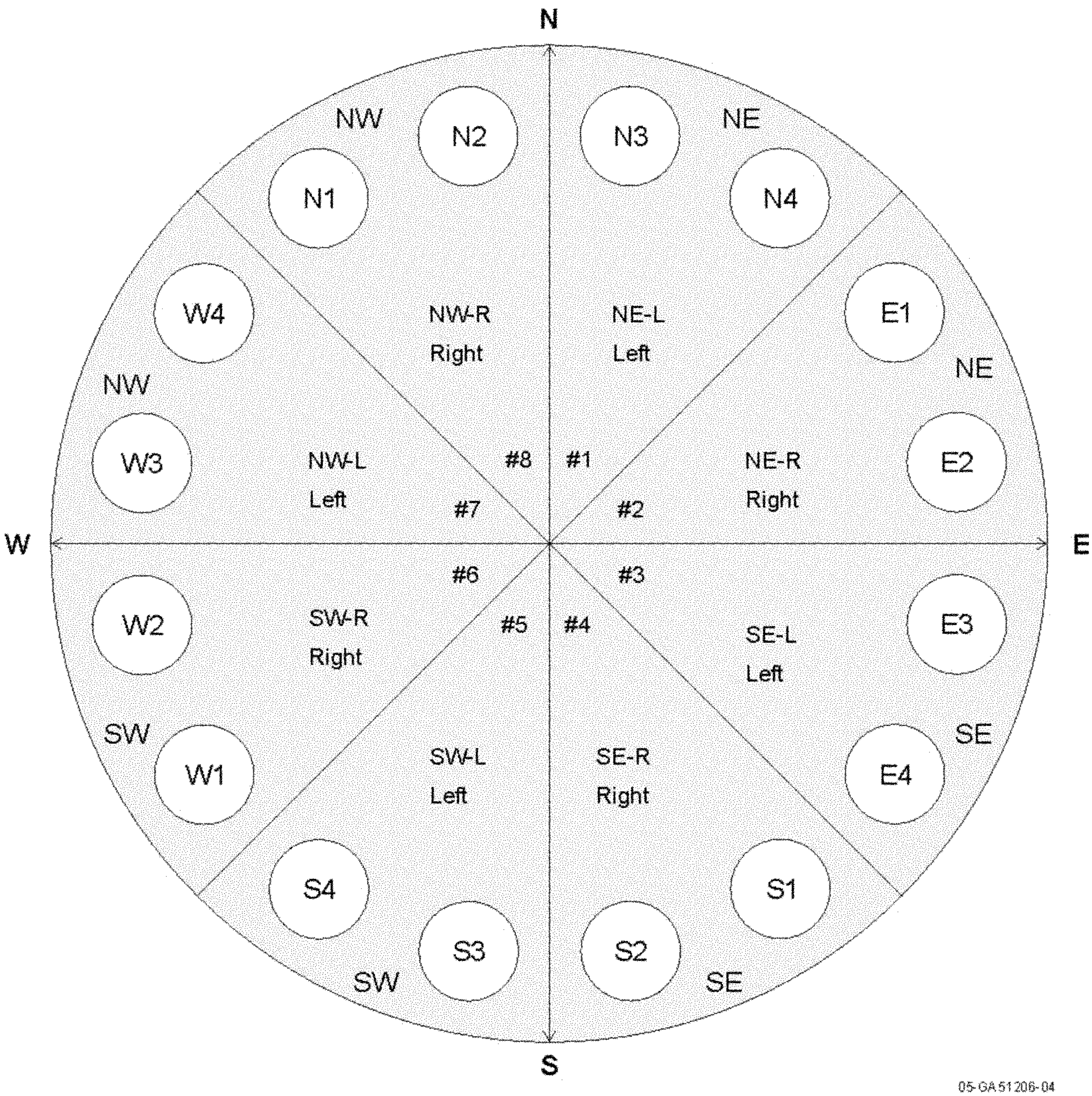
7.1 Background Information for Advanced Test Reactor

The ATR reactor core contains eight reflector blocks and 16 OSCCs. The relative position of the beryllium components is shown in Figures 7-1 through 7-4. Each core configuration is composed of two reflector blocks and four OSCCs per lobe. The four outer lobes of the reactor are identified as northwest (NW), NE (NE), southeast (SE), and southwest (SW). Looking from the center of the core outward, each lobe is split into two parts, a left side and a right side. For example, the block in the right side of the NE lobe is identified as NE-R. In Core 3 (see Figure 7-3), the block in position NE-R has the serial number (SN) 010R. The actual serial number engraved on this block is 010. The "R" is not a part of the block's serial number, but is included to distinguish between left and right blocks with the same three-digit number. For example, Block 018 in Core 3 (e.g., 018L in NW-L) has the same three-digit serial number as Block 018 in Core 4 (e.g., 018R in SW-R). Another example is the blocks located in NE-L and SE-R of Core 4. In this last case, both blocks have the same serial number 017 and could not be distinguished between each other unless the "L" or "R" label is included with its serial number.

Note that in some documents, the position of a specific beryllium block in the ATR core might be described in different terms. For instance, Block 010R in NE-R (Core 3) might be referred to as east-right or the block in reactor position number 2, or the block at location E1E2 (where E1 and E2 represent the OSCC positions within this block). See Figures 7-1 through 7-4 for the general relationship describing these various types of notation. The notation that is used in the following analysis is the lobe position (NW, NE, SE, or SW) followed by a left (L) or right (R) identifier. In many cases, the serial numbers of buried blocks are not known. For example, based on Figure 7-2, the beryllium block in Core Position No. 1 (e.g., N3N4) of Core 2 is identified as Block NE-L with no serial number. The block that was in the reactor at this location was disposed of in the SDA and did have a serial number, but this information has since been lost. Because the serial number of this particular block is not known, any reference to it is made based on its core and lobe position.

Though the ATR beryllium blocks have serial numbers, the identity of those blocks from Core 1 has been lost. The position of six of the blocks disposed of from Core 2 (see Figure 7-2) also has been lost. The two blocks (i.e., 11R and 15L) from Core 2, and shown in Figure 7-2, currently reside in the canal. These two blocks are known to have come from Core 2 because they lack saw cuts on their exterior surfaces. Though the blocks from Core 1 also did not have saw cuts, it is known that Blocks 11R and 15L could not have come from Core 1 since all blocks from Core 1 were disposed of in the SDA on or about December 1, 1976. Note that horizontal saw cuts were machined into the beryllium blocks that were placed in Cores 3, 4, and the current Core 5 configuration. These saw cuts were made to relieve stress resulting from internal gas buildup.

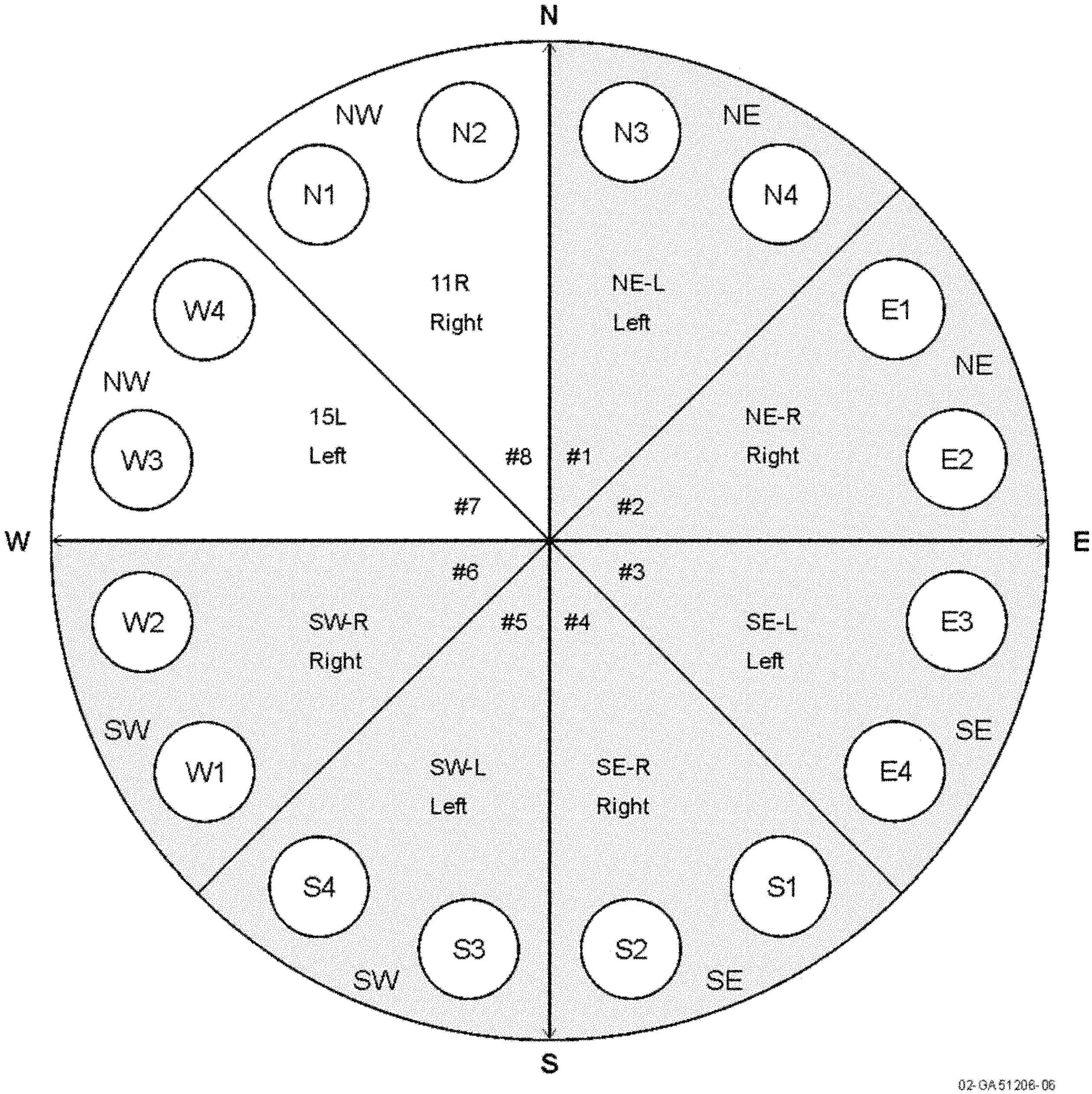
The RWMC disposal records indicate that the ATR beryllium blocks and OSCCs were disposed of during the following four campaigns: November through December 1976, eight blocks from Core 1 and 0 OSCCs; May through June 1977, six blocks from Core 2 and no (0) OSCCs (two blocks having no saw cuts still reside in the canal from Core 2); August through September 1987, nine OSCCs were disposed of (all from the Cores 1 and 2 irradiation period); May through July 1993, six blocks from Core 3 and 0 OSCCs. A total of 20 blocks and nine OSCCs were disposed of in the SDA from 1976 through 1993. A total of 12 blocks (eight from Core 4, two from Core 3, and two from Core 2) and 39 OSCCs currently remain in the ATR canal.



All blocks for Core 1 were disposed of in the SDA on or about December 1, 1976.

The serial numbers for the disposed blocks and their specific loading configuration is not known.

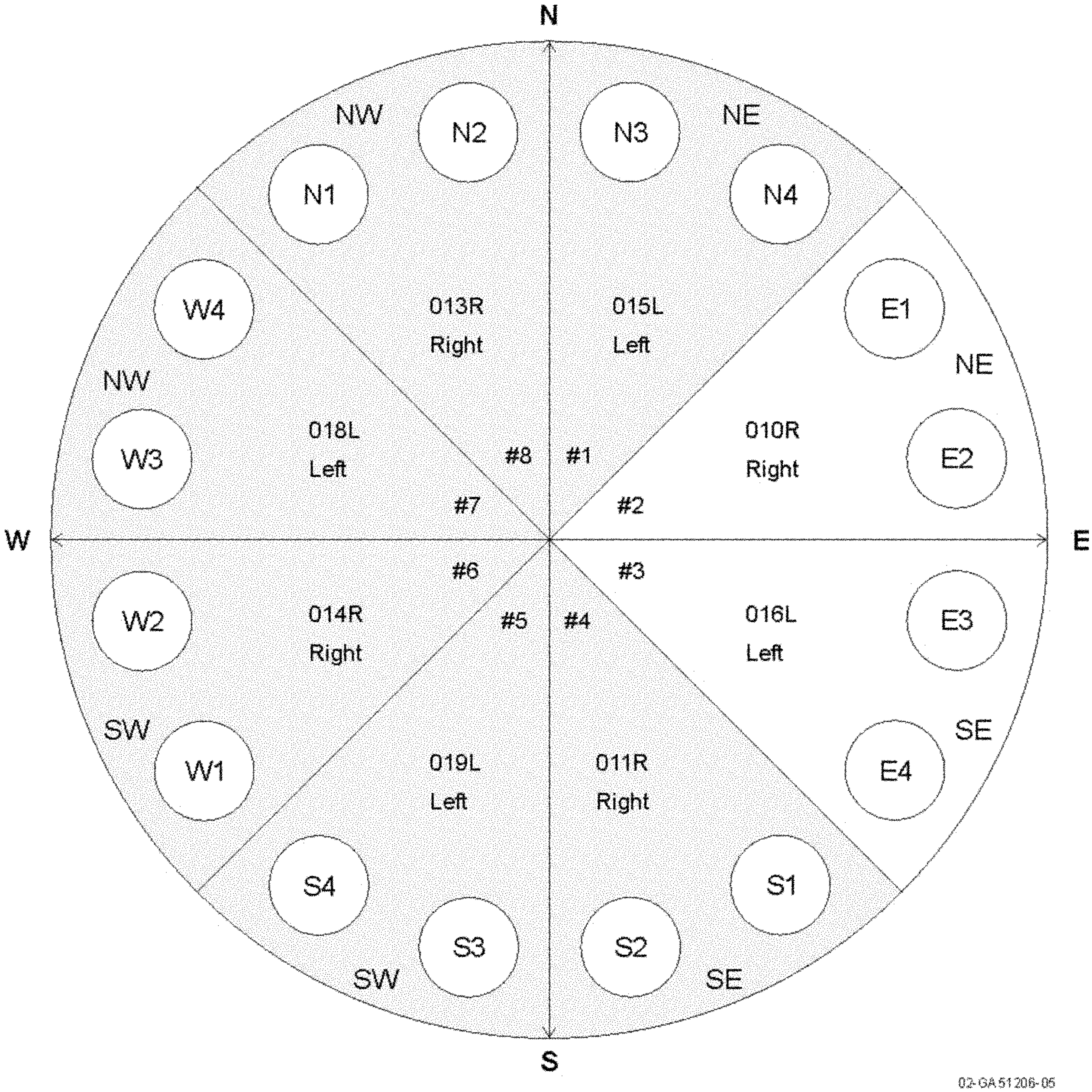
Figure 7-1. Beryllium reflector loading for the Advanced Test Reactor Core 1.



Shaded blocks were disposed of in the SDA on or about June 1, 1977.

Figure 7-2. Estimated beryllium reflector loading for Advanced Test Reactor Core 2.

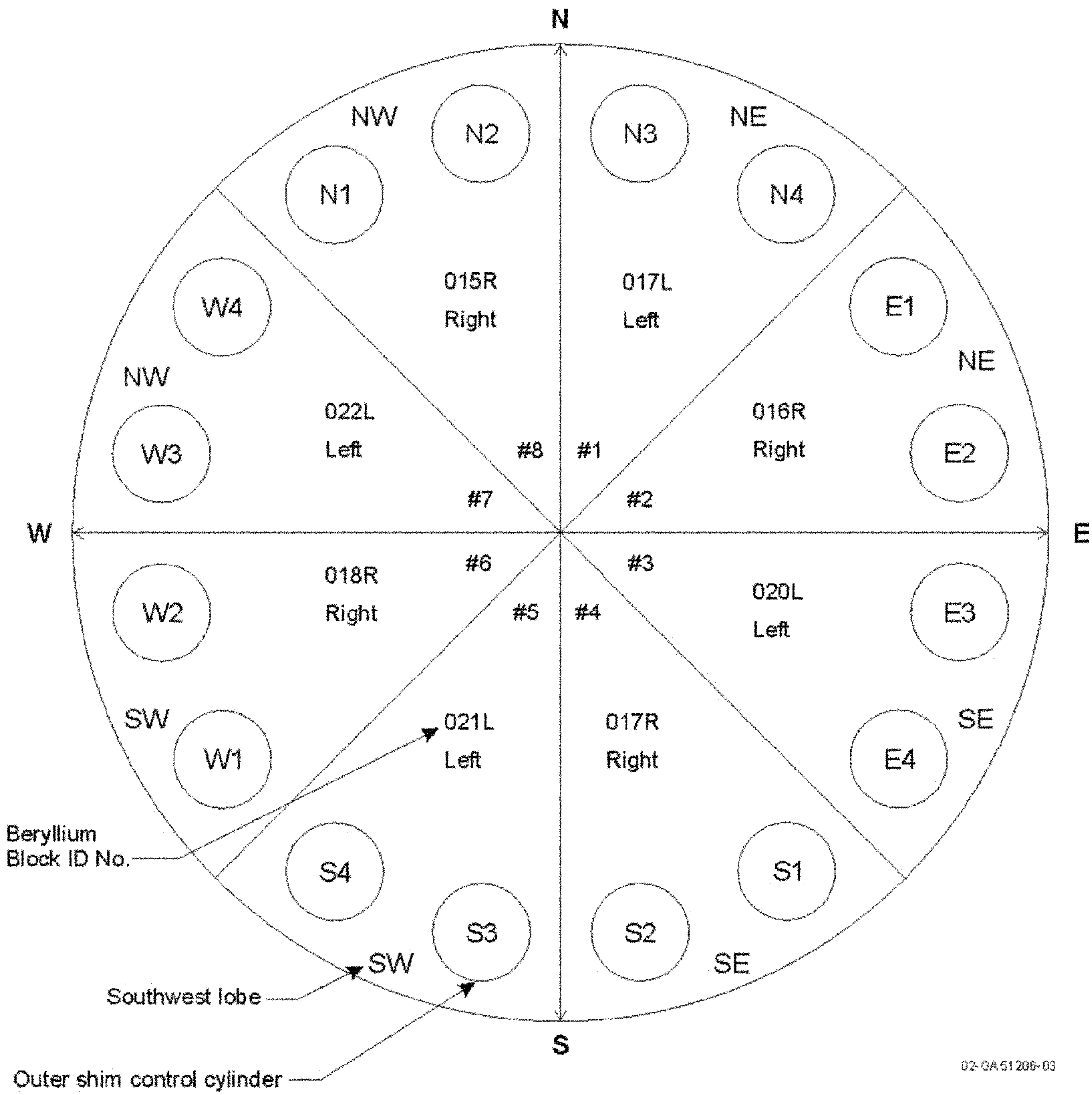
Note: All blocks from this core, except for those in the NW lobe, were disposed of in the SDA around June 1, 1977. Serial numbers of the six blocks disposed of are not known. Blocks 11R and 15L remain in the ATR canal. The irradiation positions for 11R and 15L are assumed to be from the NW lobe, but this is not certain.



Shaded blocks were disposed of in the SDA on or about July 1, 1993.

Figure 7-3. Beryllium reflector loading for Advanced Test Reactor Core 3.

Note: Six of the eight blocks from Core 3 were disposed of in the SDA around July 1, 1993. Blocks 010R and 016L remain in the ATR canal. The core positions of all blocks in Core 3 are known.



All blocks are currently stored in the ATR canal.

Figure 7-4. Beryllium reflector loading for Advanced Test Reactor Core 4.

Note: All of these blocks and outer shim control cylinders are in the Advanced Test Reactor canal. None were disposed of. The core positions of all blocks from Core 4 are known.

The 39 OSCCs remaining in the canal result from the following activities: seven from the Cores 1 and 2 irradiation, 16 from Core 3, and 16 from Core 4. Note that the OSCCs from Core 1 were reused in Core 2, but the beryllium blocks were not reused. A total of 32 blocks and 48 OSCCs were irradiated from Cores 1 through 4: eight blocks from each core, and 16 OSCCs from each of three cores (2, 3, and 4). The above disposal history is consistent with information reported in Logan (see Footnote A). However, during each disposal campaign, specific block serial numbers and reactor positional information were not recorded. Therefore, the exact disposal dates of each specific block or OSCCs are not known because actual shipments were made over several months. To simplify the computer analysis, the ORIGEN2 calculations were performed with decay times computed to average disposal dates for each major campaign. For example, December 1, 1976, was used for the eight blocks disposed of from Core 1. June 1, 1977, was used for the six blocks disposed of from Core 2. September 1, 1987, was used for the nine OSCCs disposed of from Cores 1 and 2. July 1, 1993, was used for the six blocks disposed of from Core 3. In addition to these disposal dates, all calculations were decayed out to September 15, 2001. This date represents a common reference point, which happens to approximate the time at which the first set of measured TRU data was received from Argonne National Laboratory-West (ANL-W) for Block 010R. The common decay time also allowed all results to be compared against the same time instead of different disposal time periods.

Two of the 12 reflector blocks in the canal are of the Core 1 or 2 design. These two reflector blocks can be distinguished from the newer blocks by the presence of 36 cooling holes and the absence of saw cuts. No specific documentation has been found that identifies what quadrant (i.e., lobe) these blocks were installed in, nor whether either or both came from Core 1 or from Core 2; however, based on their high serial numbers, it is likely that these reflector blocks came from Core 2. For modeling purposes, the position of the two blocks remaining in the canal were assumed to be from the NW lobe of Core 2 (as shown in Figure 7-2); however, their exact location is not certain. This means that the six blocks disposed of from Core 2 are postulated to come from the NE, SE, and SW lobes.

7.2 Advanced Test Reactor Power History

The basic irradiation history, average power data, total neutron flux, core configuration, and disposal (decay) dates are shown in Table 7-1. The data in Table 7-1 apply to all of the 32 beryllium blocks that were used during the last four core loadings. Information on the OSCCs is not explicitly shown in Table 7-1; however, the OSCC data are linked with the specific reflector blocks that contained them and can be determined from the reflector block data. The OSCC data can be determined from Table 7-1 with the knowledge that the nine disposed of OSCCs came from Core 2, but also were irradiated during Core 1. That is, the reflector blocks from Core 1 were removed during the first Core CIC, and a new set of reflector blocks were installed in Core 2, but the 16 OSCCs from Core 1 were reused in Core 2. Therefore, the first set of OSCCs saw two short core irradiations while the reflector blocks were removed during each CIC. Consequently, during the four core irradiation periods, the ATR has removed 32 blocks (8×4) and 48 OSCCs (16×3). However, only 20 blocks and nine OSCCs have been disposed of in the SDA.

Other key information needed to complete the computer modeling of the reflector blocks and OSCCs are, (1) the elemental composition of the beginning-of-life condition of the beryllium metal used in the ATR components, and (2) the best-estimate neutron cross sections that apply to this material. The assumed elemental composition of disposed of ATR beryllium is shown in Table 7-2. This information is discussed in the next section. The cross-section data were obtained from MCNP4B calculations discussed in Section 6.

Table 7-1. Irradiation history and reactor power data for the Advanced Test Reactor beryllium blocks disposed of from Cores 1, 2, 3, and 4.

Block Serial Number or Core Position	EG&G[a] Material Number	Core Loading	Initial Irradiation Date	Final Core Irradiation Date	Location	Modeled Disposal Date	Reactor Operation (days)	Total Core (MWd)	Lobe (MWd)	Average Block Total Flux	Average (MW)
Blocks in the Canal											
15L[b] no saw cuts	Unknown	2	2/5/1973	4/11/1977	ATR canal	Not disposed of	1,526	141,240	27,895	1.6083E+14	18.28
11R[b] no saw cuts	Unknown	2	2/5/1973	4/11/1977	ATR canal	Not disposed of	1,526	153,734	30,362	1.7506E+14	19.90
010R	Unknown	3	8/9/1977	2/2/1986	ATR canal	Not disposed of	3,099	305,241	47,259	1.3417E+14	15.25
016L	023	3	8/9/1977	2/2/1986	ATR canal	Not disposed of	3,099	305,241	72,984	2.0720E+14	23.55
015R	022	4	5/18/1986	2/27/1994	ATR canal	Not disposed of	2,842	267,247	41,565	1.2868E+14	14.63
016R	023	4	5/18/1986	2/27/1994	ATR canal	Not disposed of	2,842	267,247	41,883	1.2966E+14	14.74
017L	024	4	5/18/1986	2/27/1994	ATR canal	Not disposed of	2,842	267,247	41,883	1.2966E+14	14.74
017R	024	4	5/18/1986	2/27/1994	ATR canal	Not disposed of	2,842	267,247	68,710	2.1271E+14	24.18
018R	021	4	5/18/1986	2/27/1994	ATR canal	Not disposed of	2,842	267,247	57,389	1.7766E+14	20.19
020L	026	4	5/18/1986	2/27/1994	ATR canal	Not disposed of	2,842	267,247	68,710	2.1271E+14	24.18
021L	027	4	5/18/1986	2/27/1994	ATR canal	Not disposed of	2,842	267,247	57,389	1.7766E+14	20.19
022L	028	4	5/18/1986	2/27/1994	ATR canal	Not disposed of	2,842	267,247	41,565	1.2868E+14	14.63
Blocks at the RWMC	Lobe										
NW-L	NW	1	2/1/1968	9/9/1972	RWMC	12/01/76	1,682	141,240	28,894	1.5114E+14	17.178
NW-R	NW	1	2/1/1968	9/9/1972	RWMC	12/01/76	1,682	141,240	28,894	1.5114E+14	17.178
NE-L	NE	1	2/1/1968	9/9/1972	RWMC	12/01/76	1,682	141,240	27,967	1.4629E+14	16.627
NE-R	NE	1	2/1/1968	9/9/1972	RWMC	12/01/76	1,682	141,240	27,967	1.4629E+14	16.627
SW-L	SW	1	2/1/1968	9/9/1972	RWMC	12/01/76	1,682	141,240	27,978	1.4635E+14	16.634
SW-R	SW	1	2/1/1968	9/9/1972	RWMC	12/01/76	1,682	141,240	27,978	1.4635E+14	16.634
SE-L	SE	1	2/1/1968	9/9/1972	RWMC	12/01/76	1,682	141,240	28,017	1.4655E+14	16.657
SE-R	SE	1	2/1/1968	9/9/1972	RWMC	12/01/76	1,682	141,240	28,017	1.4655E+14	16.657
NE-L	NE	2	2/5/1973	4/11/1977	RWMC	06/01/77	1,526	153,734	23,625	1.3621E+14	15.482
NE-R	NE	2	2/5/1973	4/11/1977	RWMC	06/01/77	1,526	153,734	23,625	1.3621E+14	15.482
SW-L	SW	2	2/5/1973	4/11/1977	RWMC	06/01/77	1,526	153,734	36,285	2.0920E+14	23.778
SW-R	SW	2	2/5/1973	4/11/1977	RWMC	06/01/77	1,526	153,734	36,285	2.0920E+14	23.778
SE-L	SE	2	2/5/1973	4/11/1977	RWMC	06/01/77	1,526	153,734	24,357	1.4043E+14	15.961

Table 7-1. (continued).

Block Serial Number or Core Position	EG&G[a] Material Number	Core Loading	Initial Irradiation Date	Final Core Irradiation Date	Location	Modeled Disposal Date	Reactor Operation (days)	Total Core (MWd)	Lobe (MWd)	Average Block Total Flux	Average (MW)
SE-R	SE	2	2/5/1973	4/11/1977	RWMC	06/01/77	1,526	153,734	24,357	1.4043E+14	15.961
018L	NW	3	8/9/1977	2/2/1986	RWMC	07/01/93	3,099	305,241	53,924	1.5309E+14	17.400
013R	NW	3	8/9/1977	2/2/1986	RWMC	07/01/93	3,099	305,241	53,924	1.5309E+14	17.400
015L[b]	NE	3	8/9/1977	2/2/1986	RWMC	07/01/93	3,099	305,241	47,259	1.3417E+14	15.250
019L	SW	3	8/9/1977	2/2/1986	RWMC	07/01/93	3,099	305,241	60,205	1.7092E+14	19.427
014R	SW	3	8/9/1977	2/2/1986	RWMC	07/01/93	3,099	305,241	60,205	1.7092E+14	19.427
011R	SE	3	8/9/1977	2/2/1986	RWMC	07/01/93	3,099	305,241	72,984	2.0720E+14	23.551

ATR = Advanced Test Reactor L = left MW = megawatt MWd = megawatt-day NE = northeast NW = northwest R = right
RWMC = Radioactive Waste Management Complex SE = southeast SW = southwest

a. EG&G Idaho is a former contractor operator at the Idaho National Engineering and Environmental Laboratory.

b. Blocks 11R and 011R, as well as 15L and 015L, represent different serial numbers and different blocks.

The OSCCs were modeled using the information shown in Table 7-1 for the Core-1 reflector blocks. The OSCC operational data were determined as follows: (1) all nine OSCCs that were disposed of in 1987 came from the Cores 1 and 2 irradiation period. However, Cores 1 and 2 contained 16 OSCCs. Because which nine of the 16 OSCCs were actually sent to disposal is unknown, 9/16 of the entire Core 1 and 2 inventory were assumed to be disposed of. That is, an ORIGEN2 model was constructed for an entire core loading of 16 OSCCs. These OSCCs were irradiated from February 1, 1968, to September 9, 1972, (during Core 1), decayed to February 5, 1973, (the startup of Core 2), and then irradiated to April 11, 1977 (during Core 2). These results were then decayed to September 1, 1987, the assumed disposal date for the 9 OSCCs, and also decayed to September 15, 2001, the common reference time period.

7.3 Elemental Composition of Advanced Test Reactor Beryllium

The chemical composition (both primary and trace elements) of the ATR beryllium blocks and OSCCs was determined from a variety of sources. In general, the material composition data were determined from measured data obtained at ANL-W on beryllium samples collected from the 12 reflector blocks that currently reside in the ATR canal, or from chemical assay data reported by KBI on the ATR beryllium test reports, or from Brush Wellman chemical assay data obtained on recently purchased beryllium components. The KBI datasheets were an important source of information on the ATR beryllium material for the ATR reflector blocks and OSCCs that were manufactured for Cores 1, 2, and 3. Presently, Brush Wellman is the supplier of all newly acquired ATR beryllium components (both blocks and OSCCs) that reside in the reactor today (Core 5) and probably is the supplier of some of the beryllium components for Core 4. The chemical composition of beryllium metal varies depending on the original source of the beryllium ore. Unfortunately, the older KBI chemical assay data are not sufficiently detailed to define all trace impurities that occur in the ATR metal. For example, the KBI datasheets do not report any information on either nitrogen or uranium, though both elements have been measured at ANL-W on KBI beryllium samples obtained from the 12 ATR reflector blocks that still exist in the canal. Consequently, supplementing the KBI chemical assay data with either measured data or information from Brush Wellman was necessary to obtain a more complete elemental description of the ATR beryllium.

The measured data on the ATR beryllium, as reported by ANL-W, are shown in Appendix B. The ANL-W data were the primary source of information for the following elements: carbon, nitrogen, cobalt (Co-59 was estimated based on the measured Co-60 concentration), niobium, and uranium. The KBI assay data were the primary source of information on many elements that were not measured in the ANL-W analysis, but were reported in the KBI datasheets. To estimate the concentrations of elements that were not reported by KBI nor measured at ANL-W (or those elements that were only listed with limit-of-detection values), chemical assay information from Brush Wellman was used to supplement the KBI data. Therefore, Brush Wellman was the third source of elemental information on the ATR beryllium. Finally, in some cases, when no data could be identified, limit of detection information was assumed. For example, lithium is an element that has not been measured by ANL-W, nor is it reported by either KBI or Brush Wellman; however, a detection limit of <1.0 ppm is reported by KBI and a value of <3.0 has been reported by Brush Wellman. Therefore, for the case of the buried ATR beryllium (which consists of KBI beryllium metal), the lithium impurity concentration was assumed to be 1.00 ppm (by weight). How the best-estimate elemental impurity data were determined from the three individual data sets is illustrated in Table 7-2. The table also provides the best-estimate elemental composition for a typical ATR beryllium block (i.e., beryllium material only), as well as the average elemental assay data from KBI and Brush Wellman manufactured beryllium materials. The KBI data were obtained from data shown in Appendix A. The best-estimate elemental impurity information also is repeated in Table 7-3 with the elemental mass composition for an ATR reflector block and an OSCC.

Table 7-2. Elemental composition data for Advanced Test Reactor beryllium.

Atomic Number	Atomic Weight	Symbol	Element Name	ATR Beryllium (ppm by wt)	ANL-W (ppm by wt)	KBI Data (ppm by wt)	Brush Wellman (ppm by wt)
1	1.0079	H	Hydrogen	—	—	—	—
2	4.0026	He	Helium	—	—	—	—
3	6.9410	Li	Lithium	1.000	—	<1.000	<3.000
4	9.0122	Be	Beryllium	980667.835	—	980670.935	989390.909
5	10.8110	B	Boron	1.917	—	1.917	1.880
6	12.0110	C	Carbon	745.000	745.000	725.000	973.636
7	14.0067	N	Nitrogen	205.400	205.400	—	229.913
8	15.9994	O	Oxygen	12618.667	—	12618.667	7088.727
9	18.9984	F	Fluorine	69.167	—	69.167	35.700
10	20.1797	Ne	Neon	1425.000	—	—	1425.000
11	22.9898	Na	Sodium	0.874	—	—	0.874
12	24.3050	Mg	Magnesium	45.000	—	45.000	203.182
13	26.9815	Al	Aluminum	355.833	—	355.833	357.864
14	28.0855	Si	Silicon	364.167	—	364.167	287.955
15	30.9738	P	Phosphorus	50.000	—	—	50.000
16	32.0660	S	Sulfur	7.500	—	—	<7.500
17	35.4527	Cl	Chlorine	50.000	—	<50.000	15.000
18	39.9480	Ar	Argon	6.370	—	—	6.370
19	39.0983	K	Potassium	13.070	—	—	13.070
20	40.0780	Ca	Calcium	200.000	—	<200.00	<20.000
21	44.9559	Sc	Scandium	2.300	—	2.300	<4.000
22	47.8800	Ti	Titanium	61.667	—	61.667	62.045
23	50.9415	V	Vanadium	3.423	—	—	3.423
24	51.9961	Cr	Chromium	92.500	—	92.500	86.114
25	54.9381	Mn	Manganese	56.667	—	56.667	87.714
26	55.8470	Fe	Iron	1499.167	—	1499.167	790.545
27	58.9332	Co	Cobalt	12.000	12.000	<12.000	7.893
28	58.6900	Ni	Nickel	225.833	—	225.833	108.864
29	63.5460	Cu	Copper	87.500	—	87.500	42.541
30	65.3900	Zn	Zinc	13.000	—	<100.000	<13.000
31	69.7230	Ga	Gallium	0.859	—	—	0.859
32	72.6100	Ge	Germanium	5.000	—	—	5.000
33	74.9216	As	Arsenic	1.782	—	—	1.782
34	78.9600	Se	Selenium	2.383	—	—	2.383
35	79.9040	Br	Bromine	52.000	—	52.000	1.582
36	83.8000	Kr	Krypton	85.167	—	—	85.167
37	85.4678	Rb	Rubidium	7.767	—	—	7.767
38	87.6200	Sr	Strontium	6.000	—	—	6.000
39	88.9059	Y	Yttrium	1.000	—	—	1.000
40	91.2240	Zr	Zirconium	38.214	—	—	38.214
41	92.9064	Nb	Niobium	11.700	11.7	—	<25.000

Table 7-2. (continued).

Atomic Number	Atomic Weight	Symbol	Element Name	ATR Beryllium (ppm by wt)	ANL-W (ppm by wt)	KBI Data (ppm by wt)	Brush Wellman (ppm by wt)
42	95.9400	Mo	Molybdenum	10.000	—	<10.000	<17.000
43	98.9062	Tc	Technetium	—	—	—	—
44	101.0700	Ru	Ruthenium	5.000	—	—	5.000
45	102.9055	Rh	Rhodium	0.994	—	—	0.994
46	106.4200	Pd	Palladium	5.000	—	—	5.000
47	107.8682	Ag	Silver	2.167	—	2.167	<3.000
48	112.4110	Cd	Cadmium	1.000	—	<1.000	<2.000
49	114.8200	In	Indium	0.069	—	—	0.069
50	118.7100	Sn	Tin	3.000	—	—	3.000
51	121.7500	Sb	Antimony	0.241	—	—	0.241
52	127.6000	Te	Tellurium	47.467	—	—	47.467
53	126.9045	I	Iodine	10.000	—	<10.000	<10.000
54	131.2900	Xe	Xenon	537.333	—	—	537.333
55	132.9054	Cs	Cesium	0.201	—	—	0.201
56	137.3270	Ba	Barium	6.000	—	—	6.000
57	138.9055	La	Lanthanum	1.000	—	<1.000	<3.000
58	140.1150	Ce	Cerium	1.000	—	<1.000	<1.000
59	140.9077	Pr	Praseodymium	1.000	—	<1.000	<0.500
60	144.2400	Nd	Neodymium	5.000	—	<5.000	<0.500
61	—	Pm	Promethium	—	—	—	—
62	150.3600	Sm	Samarium	0.500	—	<0.500	<0.500
63	151.9650	Eu	Europium	0.500	—	<0.500	<0.500
64	157.2500	Gd	Gadolinium	0.200	—	<0.200	<0.500
65	158.9253	Tb	Terbium	1.000	—	<1.000	<1.000
66	162.5000	Dy	Dysprosium	0.200	—	<0.200	<0.500
67	164.9303	Ho	Holmium	1.000	—	<1.000	<0.500
68	167.2600	Er	Erbium	0.500	—	<0.500	<0.500
69	168.9342	Tm	Thulium	0.500	—	<0.500	<0.500
70	173.0400	Yb	Ytterbium	0.200	—	<0.200	<1.000
71	174.9670	Lu	Lutetium	0.667	—	<0.667	<1.000
72	178.4900	Hf	Hafnium	0.423	—	—	0.423
73	180.9479	Ta	Tantalum	0.433	—	—	0.433
74	183.8500	W	Tungsten	76.214	—	—	<76.214
75	186.2070	Re	Rhenium	0.644	—	—	<0.644
76	190.2000	Os	Osmium	0.637	—	—	<0.637
77	192.2200	Ir	Iridium	0.005	—	—	<0.005
78	195.0800	Pt	Platinum	101.867	—	—	<101.867
79	196.9665	Au	Gold	24.800	—	—	24.800
80	200.5900	Hg	Mercury	4.073	—	—	<4.073
81	204.3833	Tl	Thallium	25.000	—	—	<25.000
82	207.2000	Pb	Lead	1.000	—	<1.000	<20.000
83	208.9804	Bi	Bismuth	—	—	—	<5.000

Table 7-2. (continued).

Atomic Number	Atomic Weight	Symbol	Element Name	ATR Beryllium (ppm by wt)	ANL-W (ppm by wt)	KBI Data (ppm by wt)	Brush Wellman (ppm by wt)
84	—	Po	Polonium	—	—	—	—
85	—	At	Astatine	—	—	—	—
86	—	Rn	Radon	—	—	—	—
87	—	Fr	Francium	—	—	—	—
88	—	Ra	Radium	—	—	—	—
89	—	Ac	Actinium	—	—	—	—
90	232.0381	Th	Thorium	0.438	—	—	<0.438
91	—	Pa	Protactinium	—	—	—	—
92	238.0289	U	Uranium	30.000	30.000	—	71.503
			Total	1,000,000.0002			

ANL-W=Argonne National Laboratory-West ATR=Advanced Test Reactor KBI =Kawecki Berylco Industries

Table 7-3. Best-estimate elemental composition of Kawecki Berylco Industries beryllium.

Element Symbol	Element Name	Number	Atomic Weight	KBI Beryllium Concentration (ppm by wt)	Input Mass for a 81,420-g Block Mass (g)	Input Mass for a 54,431-g OSCC Mass (g)
H	Hydrogen	1	1.0079	—	—	—
He	Helium	2	4.0026	—	—	—
Li	Lithium	3	6.9410	1.000	0.081	0.054
Be	Beryllium	4	9.0122	980,667.835	79,845.975	53,378.731
B	Boron	5	10.8110	1.917	0.156	0.104
C	Carbon	6	12.0110	745.000	60.658	40.551
N	Nitrogen	7	14.0067	205.400	16.724	11.180
O	Oxygen	8	15.9994	12,618.667	1,027.412	686.847
F	Fluorine	9	18.9984	69.167	5.632	3.765
Ne	Neon	10	20.1797	1,425.000	116.024	77.564
Na	Sodium	11	22.9898	0.874	0.071	0.048
Mg	Magnesium	12	24.3050	45.000	3.664	2.449
Al	Aluminum	13	26.9815	355.833	28.972	19.368
Si	Silicon	14	28.0855	364.167	29.650	19.822
P	Phosphorus	15	30.9738	50.000	4.071	2.722
S	Sulfur	16	32.0660	7.500	0.611	0.408
Cl	Chlorine	17	35.4527	50.000	4.071	2.722
Ar	Argon	18	39.9480	6.370	0.519	0.347
K	Potassium	19	39.0983	13.070	1.064	0.711
Ca	Calcium	20	40.0780	200.000	16.284	10.886
Sc	Scandium	21	44.9559	2.300	0.187	0.125
Ti	Titanium	22	47.8800	61.667	5.021	3.357
V	Vanadium	23	50.9415	3.423	0.279	0.186
Cr	Chromium	24	51.9961	92.500	7.531	5.035
Mn	Manganese	25	54.9381	56.667	4.614	3.084
Fe	Iron	26	55.8470	1,499.167	122.062	81.601
Co	Cobalt	27	58.9332	12.000	0.977	0.653
Ni	Nickel	28	58.6900	225.833	18.387	12.292
Cu	Copper	29	63.5460	87.500	7.124	4.763
Zn	Zinc	30	65.3900	13.000	1.058	0.708
Ga	Gallium	31	69.7230	0.859	0.070	0.047
Ge	Germanium	32	72.6100	5.000	0.407	0.272
As	Arsenic	33	74.9216	1.782	0.145	0.097
Se	Selenium	34	78.9600	2.383	0.194	0.130
Br	Bromine	35	79.9040	52.000	4.234	2.830
Kr	Krypton	36	83.8000	85.167	6.934	4.636
Rb	Rubidium	37	85.4678	7.767	0.632	0.423
Sr	Strontium	38	87.6200	6.000	0.489	0.327
Y	Yttrium	39	88.9059	1.000	0.081	0.054
Zr	Zirconium	40	91.2240	38.214	3.111	2.080
Nb	Niobium	41	92.9064	11.700	0.953	0.637

Table 7-3. (continued).

Element Symbol	Element Name	Number	Atomic Weight	KBI Beryllium Concentration (ppm by wt)	Input Mass for a 81,420-g Block Mass (g)	Input Mass for a 54,431-g OSCC Mass (g)
Mo	Molybdenum	42	95.9400	10.000	0.814	0.544
Tc	Technetium	43	98.9062	—	—	—
Ru	Ruthenium	44	101.0700	5.000	0.407	0.272
Rh	Rhodium	45	102.9055	0.994	0.081	0.054
Pd	Palladium	46	106.4200	5.000	0.407	0.272
Ag	Silver	47	107.8682	2.167	.176	0.118
Cd	Cadmium	48	112.4110	1.000	0.081	0.054
In	Indium	49	114.8200	0.069	0.006	0.004
Sn	Tin	50	118.7100	3.000	0.244	0.163
Sb	Antimony	51	121.7500	0.241	0.020	0.013
Te	Tellurium	52	127.6000	47.467	3.865	2.584
I	Iodine	53	126.9045	10.000	0.814	0.544
Xe	Xenon	54	131.2900	537.333	43.750	29.248
Cs	Cesium	55	132.9054	0.201	0.016	0.011
Ba	Barium	56	137.3270	6.000	0.489	0.327
La	Lanthanum	57	138.9055	1.000	0.081	0.054
Ce	Cerium	58	140.1150	1.000	0.081	0.054
Pr	Praseodymium	59	140.9077	1.000	0.081	0.054
Nd	Neodymium	60	144.2400	5.000	0.407	0.272
Pm	Promethium	61	144.9145	—	—	—
Sm	Samarium	62	150.3600	0.500	0.041	0.027
Eu	Europium	63	151.9650	0.500	0.041	0.027
Gd	Gadolinium	64	157.2500	0.200	0.016	0.011
Tb	Terbium	65	158.9253	1.000	0.081	0.054
Dy	Dysprosium	66	162.5000	0.200	0.016	0.011
Ho	Holmium	67	164.9303	1.000	0.081	0.054
Er	Erbium	68	167.2600	0.500	0.041	0.027
Tm	Thulium	69	168.9342	0.500	0.041	0.027
Yb	Ytterbium	70	173.0400	0.200	0.016	0.011
Lu	Lutetium	71	174.9670	0.667	0.054	0.036
Hf	Hafnium	72	178.4900	0.423	0.034	0.023
Ta	Tantalum	73	180.9479	0.433	0.035	0.024
W	Tungsten	74	183.8500	76.214	6.205	4.148
Re	Rhenium	75	186.2070	0.644	0.052	0.035
Os	Osmium	76	190.2000	0.637	0.052	0.035
Ir	Iridium	77	192.2200	0.005	—	—
Pt	Platinum	78	195.0800	101.867	8.294	5.545
Au	Gold	79	196.9665	24.800	2.019	1.350
Hg	Mercury	80	200.5900	4.073	0.332	0.222
Tl	Thallium	81	204.3833	25.000	2.036	1.361
Pb	Lead	82	207.2000	1.000	0.081	0.054

Table 7-3. (continued).

Element Symbol	Element Name	Number	Atomic Weight	KBI Beryllium Concentration (ppm by wt)	Input Mass for a 81,420-g Block Mass (g)	Input Mass for a 54,431-g OSCC Mass (g)
Bi	Bismuth	83	208.9804	—	—	—
Po	Polonium	84	—	—	—	—
At	Astatine	85	—	—	—	—
Rn	Radon	86	—	—	—	—
Fr	Francium	87	—	—	—	—
Ra	Radium	88	—	—	—	—
Ac	Actinium	89	—	—	—	—
Th	Thorium	90	232.0381	0.438	0.036	0.024
Pa	Protactinium	91	—	—	—	—
U	Uranium	92	238.0289	30.000	2.443	1.633
			Totals	1,000,000.000	81,420.000	54,431.000

KBI = Kawecki Berylco Industries OSCC=outer shim control cylinder

The elemental mass data from Table 7-3 appear in the ORIGEN2 models for these two components. An ORIGEN2 input deck for a reflector block from Core 1 is shown in Appendix C. An ORIGEN2 input deck for the OSCCs from Cores 1 and 2 irradiation period is shown in Appendix D. The elemental mass data from Table 7-3 are included with both ORIGEN2 input decks.

The best-estimate elemental concentration data for beryllium metal, as shown in Tables 7-2 and 7-3 are slightly different than those previously reported in Gay (see Footnote A). The reason for these differences is that the previous results apply to beryllium metal obtained from Brush Wellman, while the current best-estimated data are based on KBI beryllium metal. Some of the measured data from ANL-W were not available for the Gay report (see Footnote A).

One important assumption that has to be made in the computer code analysis is that the elemental concentrations are uniformly distributed throughout each reflector block or OSCC (before irradiation). Though no specific information from KBI affirms this assumption, some supporting data from Brush Wellman on nitrogen data support the assumption. Information from Brush Wellman for S-65C grade beryllium indicates that the nitrogen concentration is evenly distributed throughout the pressed billets. Because there does not appear to be any physical reason for the existence of large concentration gradients within the manufactured billets, all elemental impurities are assumed to be uniformly distributed throughout each beryllium component (before irradiation). After irradiation, newly generated isotopes (and depletion of parent isotopes) will produce different concentrations throughout the irradiated block. For this reason, the first set of collected test samples was obtained from regions of each reflector block (e.g., Site 1) that minimized the effects of neutron irradiation, allowing for an accurate determination of its beginning-of-life conditions.

7.4 Advanced Test Reactor Reflector Block and Outer Shim Control Cylinders Physical Descriptions

A schematic of a right-side reflector block, 010R, in a vertical orientation is depicted in Figure 6-1. A horizontal cross section of a left-side reflector block with some important dimensions is shown in Figure 7-5. A schematic of two attached ATR reflector blocks is shown in Figure 7-6. Note that the topside of both blocks is shown on the right side of this figure. In the configuration shown in Figure 7-5, the right block is identified as Part 419609-1 and the left block is shown as Part 419609-2. The average weight of the beryllium metal contained in each reflector block (i.e., without its associated nonberyllium hardware) is approximately 81,420 g (179.5 lb). The density of beryllium metal is 1.85 g/cm^3. Therefore, the metal volume of a reflector block is approximately 44,000 cm^3 (0.044 m^3). The height of each block is 130 cm (51 in.) and the active ATR core height is 122 cm (48 in.). Therefore, portions of each reflector block extend above the reactor fuel. The cross-sectional (metal) area of an ATR reflector block is approximately 340 cm^2 (53 in.^{2}).

The weight of a single ATR reflector block without the nonberyllium hardware has been measured at Speedring, currently known as Axsys Technologies, Cullman, Alabama, (the company that currently machines the ATR beryllium blocks) to be 81,420 g (179.5 lb). This weight represents a current block design; that is, one with saw cuts. Blocks without saw cuts are estimated to weigh about 81,650 g (180 lb). To simplify the computer modeling details (especially the input mass of elements that define the composition of a block), and have one model apply to both types of reflector block configurations, all ATR reflector blocks (both with and without saw cuts) were assumed to have a beryllium weight of 81,420 g (179.5 lb).

The estimated beryllium weight of an OSCC is 54,400 g (120 lb) and its corresponding metal volume is about 30,000 cm^3. All new OSCCs, and most of the older OSCCs, were constructed of three separate axial sections of beryllium components (as illustrated in Figure 7-7 and 7-8).

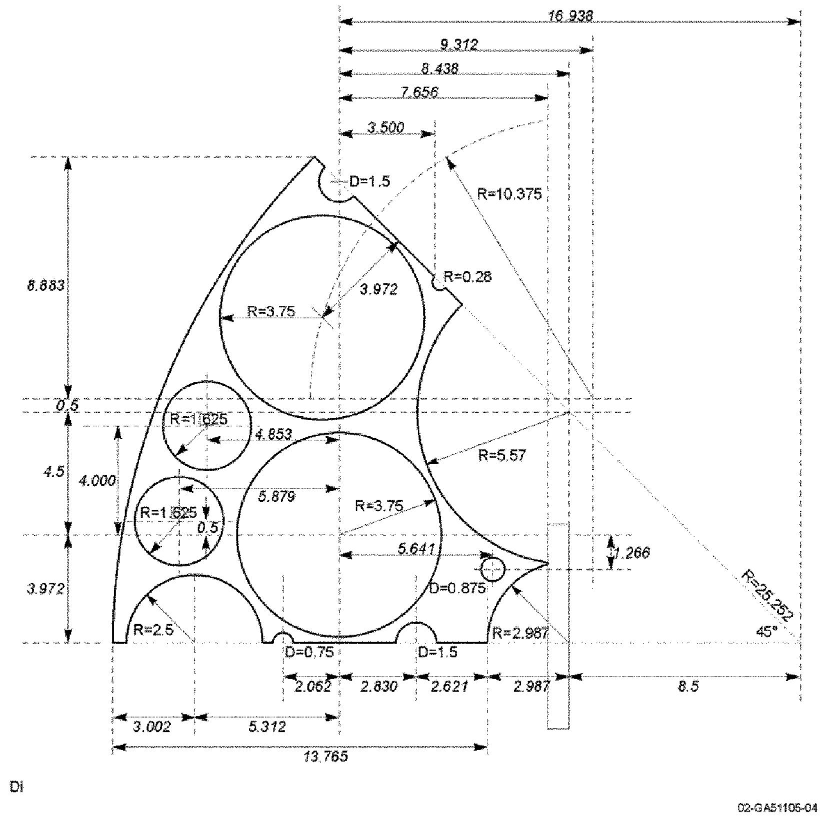


Figure 7-5. Horizontal cross section of an Advanced Test Reactor beryllium reflector block showing dimensional data. The illustrated block represents the left side of a block, assuming that the top surface is visible.

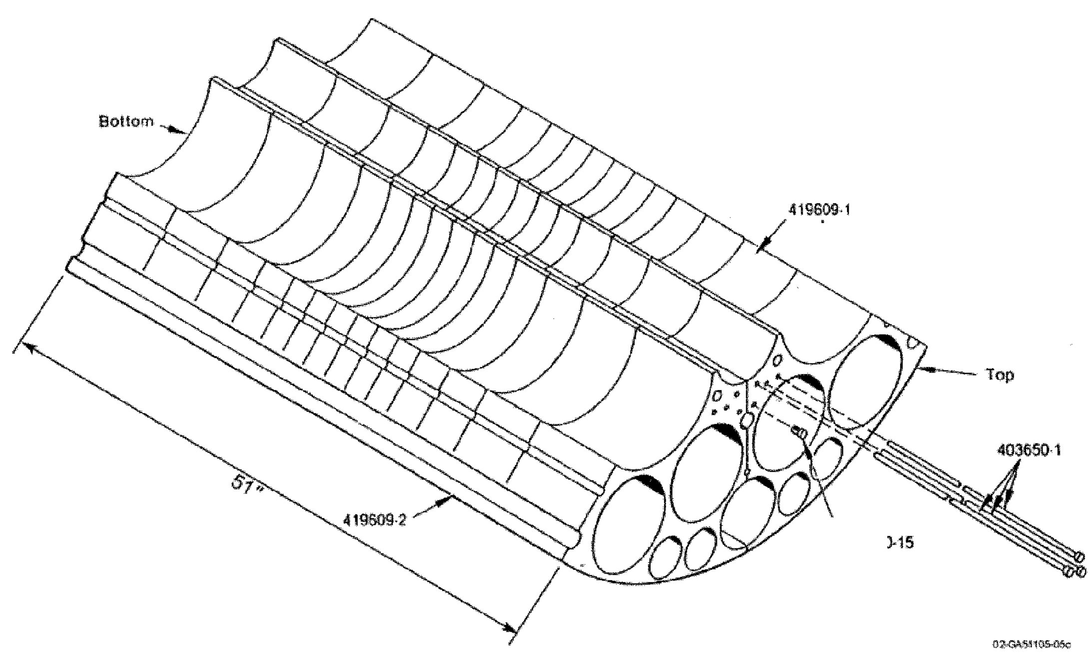


Figure 7-6. Two Advanced Test Reactor beryllium reflector blocks positioned together to form one single reflector lobe.

The height of each beryllium segment varied from approximately 39 cm (15.33 in.) for the upper and center sections, to 41 cm (16.14 in.) for the lower segment. The total height of the three beryllium sections is 119 cm (46.8 in.). Because of its component construction, each beryllium section within an OSCC has a good chance of being made from different beryllium pressings (or billets), and each section can have different chemical impurities. However, the chemical impurity data are not known for each component of each OSCC. The best-estimate composition of the ATR OSCCs was assumed to be the same as that used for the ATR beryllium blocks. In addition, these concentrations are assumed to apply uniformly to all three sections of each OSCC.

7.5 Cross-Sectional Data Used in the Oak Ridge Isotope GENeration and Depletion Code Version 2 Analysis

For the ORIGEN2 calculations, one-group neutron cross-section libraries were constructed from several different data sets. First, the INEEL standard ATR cross-section library was applied to all ORIGEN2 calculations and each radionuclide that was not otherwise explicitly modeled with a substitution data set. The substitution library was produced from MCNP4B calculations for those radionuclides: Li-6, Be-9, C-12, C-13, N-14, O-17, Co-59, Co-60, Co-61, Ni-58, Ni-59, Ni-60, Ni-61, Ni-62, Ni-63, Ni-64, Cu-63, Zn-66, Nb-93, Nb-94, Mo-94, Mo-98, Mo-99, Tc-99, Th-232, Th-233, Pa-233, U-233, U-234, U-235, U-236, U-237, U-238, U-239, U-240, Np-235, Np-236, Np-237, Np-238, Pu-237, Pu-238, Pu-239, Pu-240, Pu-241, Pu-242, Pu-243, Am-241, Am-242, Am-243, Cm-242, Cm-243, Cm-244, Cm-245, Cm-246, Cm-247, Cm-248, Bk-249, Cf-249, Cf-250, Cf-251, and Cf-252. Four explicit cross-section data sets were generated. One library was generated for the Site 1 (low-flux) region of Block 010R, one set was generated for the Site 2 (the high-flux) region of Block 010R, and another set was produced for the average region of Block 010R. A fourth set was generated for an OSCC.

The cross sections for Sites 1 and 2 were then used in the ORIGEN2 calculations that modeled these specific locations. Sites 1 and 2 calculations were then compared against measured data collected from these locations. The measured data provided some validation information, and allowed for an estimate of the accuracy of the computer model to reproduce the measured data, thereby providing a measure of the accuracy of the code to determine the total inventories of radionuclides for reflector blocks and OSCCs that were not independently measured. The block average cross-section data set was used in the ORIGEN2 calculations for Block 010R and all other reflector blocks. A separate cross-section data set was generated for the OSCCs. A sample ORIGEN2 input deck is shown in Appendix C for the ATR blocks from Core 1. This input deck includes substitution cards that define the one-group cross sections for several radionuclides of interest. Note that these cards begin with either a 204 or 908 identifier.

7.6 Oak Ridge Isotope GENeration and Depletion Code Version 2 Model for the Advanced Test Reactor Reflector Blocks

In addition to the computer models generated to determine the entire block inventories from Cores 1, 2, and 3, two specific node calculations were made for Sites 1 and 2 for Block 010R (see Figure 6-1). The purpose of the individual node calculations was to assess the ORIGEN2 model against measured data values that were obtained from these two sample locations. Comparisons of the measured data obtained from Site 1 and the ORIGEN2 calculated results are shown in Table 7-4. Two samples collected from Site 2 (Samples 82553 and 82919) were analyzed at ANL-W. Comparisons of the measured data against computer code calculated results are shown in Table 7-5 (for Sample 82553) and Table 7-6 (for Sample 82919). Note is that the measured TRU inventories at Site 2 are slightly higher than the code results.

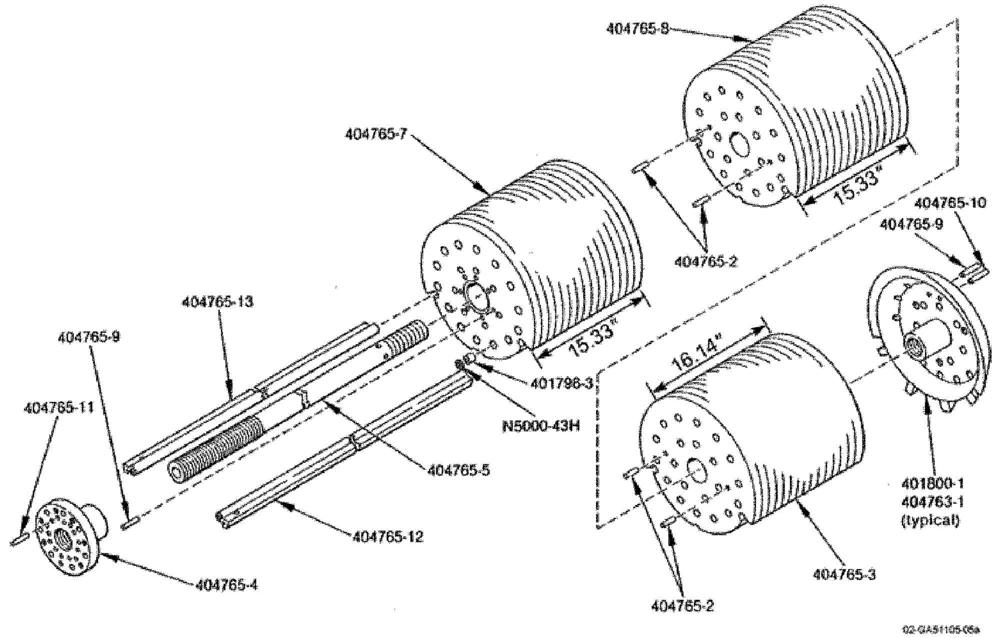


Figure 7-7. A schematic of a disassembled outer shim control cylinder showing its key components.

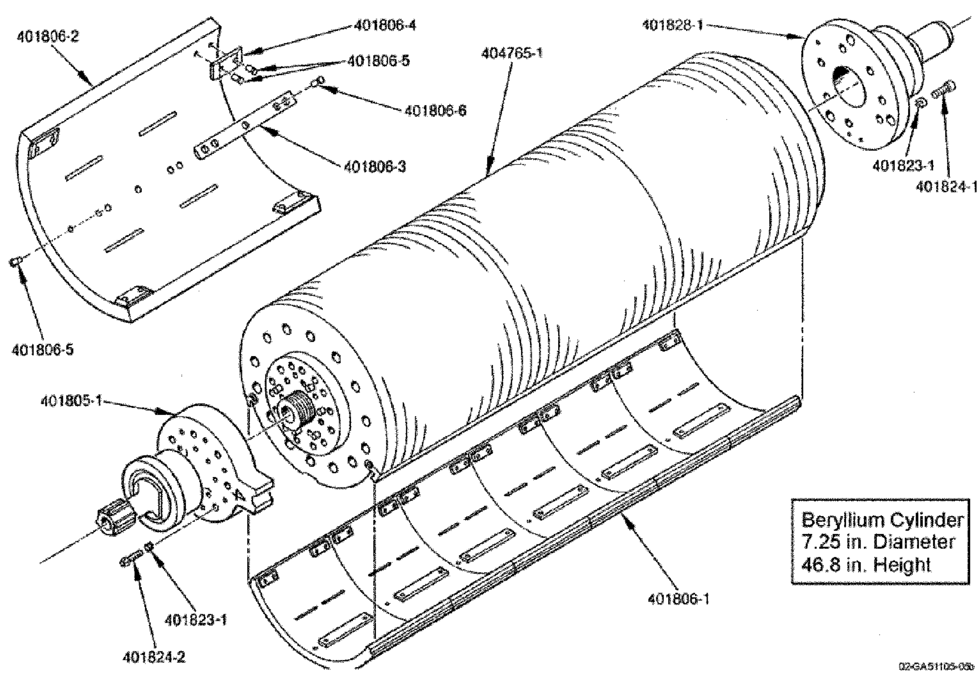


Figure 7-8. A partially assembled outer shim control cylinder.

Table 7-4. Comparison of measured Sample 79778 and Oak Ridge Isotope GENeration and Depletion Code Version 2 results for Site 1 using the best-estimate cross sections for Block 010R (Core 3, northeast lobe).

	Sample 79778					
Isotopes	Measured (µCi/g)	Measured (µg/g)	ORIGEN2 (µCi/g)	ORIGEN2 (µg/g)	Ratio Measured/ ORIGEN2	Comments
H-3	200.0	—	341.7	—	0.585	
C-14	0.61	—	1.07	—	0.570	N impurity = 203 ppm = measured data for 79778
Co-60	13.1	—	13.11	—	0.999	Estimated BOL Co impurity = 9 ppm
Cs-137	0.20	—	0.22	—	0.918	
Nb-93	—	1	—	1.00	0.998	BOL Nb-93 impurity = 1 ppm
Total U (EOL)	—	30 to 37	—	29.9	1.003 to 1.24	Estimated BOL naturally enriched U = 30 ppm
		Ratio		Ratio		
U-235/U-238	—	0.0053	—	0.0047	1.123	Natural ratio = 0.0072

TRU Isotopes	Measured (nCi/g)	Measured (ng/g)	ORIGEN2 (nCi/g)	ORIGEN2 (ng/g)	Ratio Measured/ ORIGEN2	Comments
Np-237	—	—	0.000	0.049	—	Half-life = 2,140,000 years
Pu-238	—	—	0.096	0.006	—	Half-life = 87.7 years
Pu-239	4.35	70	5.119	82.31	0.850	Half-life = 24,100 years
Pu-240	—	—	2.051	8.998	—	Half-life = 6,560 years
Pu-241	Not included	—	Not included	—	—	Pu-241 is not a TRU, half-life = 14.4 years
Pu-242	—	—	0.000	0.042	—	Half-life = 376,300 years
Pu-244	—	—	0.000	0.000	—	Half-life = 82,600,000 years, alpha decay = 99.9%
Am-241	—	—	1.296	0.377	—	Half-life = 433 years
Am-243	—	—	0.000	0.000	—	Half-life = 7,370 years
Cm-243	—	—	0.000	0.000	—	Half-life = 29 years, alpha decay = 99.76%
Cm-244	Not included	—	Not included	—	—	Cm-244 is not a TRU, half-life = 18.1 years
Cm-245	—	—	0.000	0.000	—	Half-life = 8,500 years
Cm-246	—	—	0.000	0.000	—	Half-life = 4,760 years
Cm-247	—	—	0.000	0.000	—	Half-life = 15,600,000 years
Cm-248	—	—	0.000	0.000	—	Half-life = 340,000 years, alpha decay = 92%
Total TRU	4.35	—	8.56	—	0.51	

BOL=beginning of life EOL=end of life ORIGEN2=Oak Ridge Isotope GENeration and Depletion Code Version 2
TRU=transuranic waste

Note: Flux=3.466E12 n/cm^2/second.

Table 7-5. Comparison of measured Sample 82553 and Oak Ridge Isotope GENeration and Depletion Code Version 2 results for Site 2 using the best-estimate cross sections for Block 010R (Core 3, northeast lobe).

	Sample 82553		Site 2			
Isotopes	Measured (µCi/g)	Measured (µg/g)	ORIGEN2 (µCi/g)	ORIGEN2 (µg/g)	Ratio Measured/ ORIGEN2	Comments
H-3	Not measured	Not measured	1,650,000	—	—	
C-14	Not measured	Not measured	66	—	—	N impurity = 203 ppm = measured data
Co-60	375	—	529	—	0.71	Estimated BOL Co impurity = 9 ppm
Cs-137	50	—	55	—	0.91	
Total U (EOL)	—	10.3	—	6.42	1.60	Estimated BOL naturally enriched U = 30 ppm
		Ratio		Ratio		
U-235/U-238	—	<0.00019	—	0.00020	<0.95	Natural ratio = 0.0072
TRU Isotopes	Measured (nCi/g)	Measured (µg/g)	ORIGEN2 (nCi/g)	ORIGEN2 (µg/g)	Ratio Measured/ ORIGEN2	Comments
Np-237	—	—	0.002	0.0022	—	Half-life = 2,140,000 years
Pu-238	34.3	0.002	46.66	0.0027	0.74	Half-life = 87.7 years
Pu-239	14.9	0.240	11.71	0.1882	1.27	Half-life = 24,100 years
Pu-240	52.2	0.230	56.55	0.2481	0.93	Half-life = 6,560 years
Pu-241	Not included	0.020	Not included	0.0266	0.75	Pu-241 is not a TRU, half-life = 14.4 years
Pu-242	0.6	0.150	0.742	0.1942	0.79	Half-life = 376,300 years
Pu-244	—	—	—	—	—	Half-life = 82,600,000 years, alpha decay = 99.9%
Am-241	241	0.070	102.9	0.0300	2.34	Half-life = 433 years
Am-243	41	0.205	12.03	0.0603	3.40	Half-life = 7,370 years
Cm-243	—	—	1.651	0.000032	—	Half-life = 29 years, alpha decay = 99.76%
Cm-244	Not included	0.380	Not included	0.2249	1.69	Cm-244 is not a TRU, half-life = 18.1 years
Cm-245	5.2	0.030	2.985	0.0174	1.73	Half-life = 8,500 years
Cm-246	45.6	0.150	44.270	0.1441	1.04	Half-life = 4,760 years
Cm-247	0.0006	0.007	0.001	0.0080	0.74	Half-life = 15,600,000 years
Cm-248	—	—	0.048	0.0112	—	Half-life = 340,000 years, alpha decay = 92%
Total TRU	434.8	—	279.5	—	1.56	

BOL=beginning of life EOL=end of life ORIGEN2=Oak Ridge Isotope GENeration and Depletion Code Version 2
TRU=transuranic waste

Note: Flux=6.704E14 n/cm^2/second.

Table 7-6. Comparison of measured Sample 82919 and Oak Ridge Isotope GENeration and Depletion Code Version 2 results for Site 2 using the best-estimate cross sections for Block 010R (Core 3, northeast lobe).

Isotopes	Sample 82919 Measured (µCi/g)	Sample 82919 Measured (µg/g)	Site 2 ORIGEN2 (µCi/g)	Site 2 ORIGEN2 (µg/g)	Ratio Measured/ ORIGEN2	Comments
H-3	840,000	—	1,650,000	—	0.509	
C-14	41	—	66	—	0.621	N impurity = 203 ppm = measured data
Co-60	380	—	529	—	0.718	Estimated BOL Co impurity = 9 ppm
Cs-137	51	—	55	—	0.927	
Total U (EOL)	—	8.71	—	6.42	1.35	Estimated BOL naturally enriched U = 30 ppm
		Ratio		Ratio		
U-235/U-238	—	0.0081	—	0.00020	See comment	Natural ratio = 0.0072 Probable error in the measured ANL-W result for U-235

TRU Isotopes	Measured (nCi/g)	Measured (µg/g)	ORIGEN2 (nCi/g)	ORIGEN2 (µg/g)	Ratio Measured/ ORIGEN2	Comments
Np-237	—	—<0.01	0.002	0.0022	—	Half-life = 2,140,000 years
Pu-238	61.56	0.0036	46.66	0.0027	1.32	Half-life = 87.7 years
Pu-239	13.0	0.210	11.71	0.1882	1.11	Half-life = 24,100 years
Pu-240	63.6	0.280	56.55	0.2481	1.13	Half-life = 6,560 years
Pu-241	Not included	0.020	Not included	0.0266	0.75	Pu-241 is not a TRU, half-life = 14.4 years
Pu-242	0.79	0.20	0.742	0.1942	1.06	Half-life = 376,300 years
Pu-244	—	—	—	—	—	Half-life = 82,600,000 years, alpha decay = 99.9%
Am-241	310	0.09	102.9	0.0300	3.0	Half-life = 433 years
Am-243	48	0.24	12.03	0.0603	4.0	Half-life = 7,370 years
Cm-243	—	—	1.651	0.000032	—	Half-life = 29 years, alpha decay = 99.76%
Cm-244	Not included	0.25	Not included	0.2249	1.11	Cm-244 is not a TRU, half-life = 18.1 years
Cm-245	3.4	0.02	2.985	0.0174	1.14	Half-life = 8,500 years
Cm-246	33.4	0.11	44.27	0.1441	0.97	Half-life = 4,760 years
Cm-247	0	0	0.001	0.0080	0	Half-life = 15,600,000 years
Cm-248	—	—	0.048	0.0112	—	Half-life = 340,000 years, alpha decay = 92%
Total TRU	533.4	—	279.5	—	1.91	

ANL-W=Argonne National Laboratory-West BOL=beginning of life EOL=end of life
ORIGEN2= Oak Ridge Isotope GENeration and Depletion Code Version 2 TRU = transuranic waste

Note: Flux=6.704E14 n/cm^2/second.

A detailed listing of the ORIGEN2 model for the ATR reflector blocks from Core 1 is shown in Appendix C. This computer model considered one block from each of the four lobes. Because all eight blocks from Core 1 were disposed of and the alternate blocks from each lobe would have an inventory equal to that calculated in the ORIGEN2 model, the entire inventory from Core 1 can be determined by multiplying the ORIGEN2 results by a factor of 2.

7.7 Oak Ridge Isotope GENeration and Depletion Code Version 2 Model for the Advanced Test Reactor Outer Shim Control Cylinders

A model input listing ORIGEN2 for an ATR OSCC is given in Appendix D. Only nine OSCCs have been disposed of and all of these shim cylinders have come from Core 2. Note that the OSCCs that were in Core 2 also saw irradiation in Core 1. That is, the shim cylinders were used in both Cores 1 and 2. Because it is unknown which nine of the 16 OSCCs were disposed of, the computer code model calculated the total inventory for all 16 OSCCs. The inventory for those OSCCs that were disposed of in the SDA can be determined by multiplying the total OSCC inventory by 9/16 (0.5625).

7.8 Best-Estimate Calculated Inventory Results for the Advanced Test Reactor Reflector Blocks and Outer Shim Control Cylinders

The inventories calculated using ORIGEN2 for the ATR beryllium components disposed of in the SDA are shown in Tables 7-7 through 7-16. The results for the ATR reflector blocks are specifically given in Tables 7-7 through 7-12, and the corresponding results for the ATR OSCCs are shown in Tables 7-13 and 7-14. Though the ORIGEN2 code can calculate the production and decay of several hundred radionuclides (e.g., 688 activation products, 129 actinides + daughters, and 879 fission products), only the results of the 44 most important radionuclides are listed in these tables. The selected 44 radionuclides were chosen to have the greatest potential impact.

The table values are separated into four major groups (the blocks from: Cores 1, 2, and 3; and the OSCCs from Cores 1 and 2). All results are computed for two different decay times (the specific disposal date and a common decay date of September 15, 2001). For example, the calculated inventory for the eight reflector blocks disposed of from Core 1 is shown in Table 7-7 for the disposal date of December 1, 1976, and Table 7-8 for the common decay date of September 15, 2001. The curie results shown in Columns 3, 4, 5, and 6 of Table 7-7 represent the calculated block inventories for one block located in the NW lobe of Core 1, one block from the NE lobe, one block from the SW lobe, and one block from the SE lobe. Each lobe position contains two blocks and all eight blocks were disposed of from Core 1, the total block inventory from Core 1 (e.g., the Column 7 data) can be computed as follows: The total inventory for the eight blocks disposed of from Core 1 (Column 7) equals 2 × NW lobe inventory (Column 3) + 2 × NE lobe inventory (Column 4) + 2 × SW lobe inventory (Column 5) + 2 × SE lobe inventory (Column 6). In addition to the calculated curie inventories of the 44 principal radionuclides, the calculated 10 CFR 61 (2002) sum-of-fractions rule for C-14, Ni-59, Nb-94, Tc-99, I-129, and Pu-241 are shown near the center of each table. At the bottom of these tables, the TRU concentration (nano-curies per gram) is calculated for those TRU isotopes with half-lives greater than 20 years. The total lobe megawatt-day energy generation, the total beryllium mass, and metal volume for each beryllium component also are shown at the bottom of each table.

Table 7-7. Oak Ridge Isotope GENeration and Depletion Code Version 2 calculated inventory at the estimated disposal date of December 1, 1976, for Advanced Test Reactor beryllium blocks located in Core 1.

Isotope	Half-life (years)	Lobe Northwest NW-L or NW-R (Ci per block)	Lobe Northeast NE-L or NE-R (Ci per block)	Lobe Southwest SW-L or SW-R (Ci per block)	Lobe Southeast SE-L or SE-R (Ci per block)	Total Inventory for Eight Blocks (Ci for eight blocks)
H-3	1.23E+01	1.678E+04	1.614E+04	1.615E+04	1.617E+04	1.305E+05
Be-10	1.60E+06	1.246E-01	1.206E-01	1.206E-01	1.208E-01	9.732E-01
C-14	5.73E+03	9.997E-01	9.679E-01	9.683E-01	9.696E-01	7.811E+00
Cl-36	3.01E+05	8.390E-03	8.134E-03	8.137E-03	8.148E-03	6.562E-02
Co-60	5.27E+00	9.893E+01	9.616E+01	9.620E+01	9.631E+01	7.752E+02
Ni-59	7.60E+04	2.096E-02	2.054E-02	2.054E-02	2.056E-02	1.652E-01
Ni-63	1.00E+02	3.743E+00	3.638E+00	3.639E+00	3.644E+00	2.933E+01
Sr-90	2.91E+01	3.223E-01	3.122E-01	3.123E-01	3.127E-01	2.519E+00
Nb-94	2.00E+04	2.254E-03	2.188E-03	2.189E-03	2.192E-03	1.765E-02
Tc-99	2.13E+05	1.295E-04	1.256E-04	1.256E-04	1.258E-04	1.013E-03
I-129	1.57E+07	9.515E-07	9.215E-07	9.219E-07	9.231E-07	7.436E-06
Cs-137	3.02E+01	1.044E+00	1.008E+00	1.009E+00	1.010E+00	8.143E+00
Eu-152	1.35E+01	2.866E-02	3.279E-02	3.273E-02	3.255E-02	2.535E-01
Eu-154	8.59E+00	1.891E+00	1.911E+00	1.910E+00	1.910E+00	1.524E+01
10 CFR 61 (2002) Sum-of-fractions rule for:						
C-14+Ni-59+Nb-94+Tc-99+I-129 =		0.543	0.527	0.527	0.528	0.531
C-14+N-i59+Nb-94+Tc-99+I-129+ Pu-241 =		3.700	3.692	3.692	3.692	3.694
Ni-63+Sr-90+Cs-137 =		0.018	0.018	0.018	0.018	0.018
Pb-210	2.23E+01	2.308E-12	2.130E-12	2.132E-12	2.139E-12	1.742E-11
Ra-226	1.60E+03	7.251E-13	7.087E-13	7.089E-13	7.096E-13	5.705E-12
Ra-228	5.76E+00	2.126E-09	2.133E-09	2.132E-09	2.132E-09	1.705E-08
Ac-227	2.18E+01	5.335E-09	5.278E-09	5.279E-09	5.281E-09	4.235E-08
Th-228	1.91E+00	8.569E-06	8.202E-06	8.206E-06	8.221E-06	6.640E-05
Th-229	7.30E+03	4.976E-09	4.969E-09	4.969E-09	4.969E-09	3.977E-08
Th-230	7.54E+04	3.042E-10	2.975E-10	2.976E-10	2.979E-10	2.394E-09
Th-232	1.40E+10	3.532E-09	3.544E-09	3.544E-09	3.543E-09	2.833E-08
Pa-231	3.28E+04	2.960E-08	2.924E-08	2.925E-08	2.926E-08	2.347E-07
U-232	7.00E+01	9.724E-06	9.306E-06	9.311E-06	9.328E-06	7.534E-05
U-233	1.59E+05	7.740E-06	7.733E-06	7.733E-06	7.734E-06	6.188E-05
U-234	2.46E+05	1.715E-06	1.684E-06	1.685E-06	1.686E-06	1.354E-05
U-235	7.04E+08	4.258E-10	4.740E-10	4.734E-10	4.712E-10	3.689E-09
U-236	2.34E+07	1.461E-07	1.469E-07	1.469E-07	1.468E-07	1.173E-06
U-238	4.47E+09	6.797E-07	6.837E-07	6.837E-07	6.835E-07	5.461E-06
Np-237	2.14E+06	1.983E-07	1.957E-07	1.957E-07	1.959E-07	1.571E-06
Pu-238	8.77E+01	1.055E-02	1.045E-02	1.045E-02	1.046E-02	8.382E-02
Pu-239	2.41E+04	2.507E-03	2.521E-03	2.521E-03	2.520E-03	2.014E-02
Pu-240	6.56E+03	4.137E-03	4.147E-03	4.147E-03	4.147E-03	3.316E-02
Pu-241	1.44E+01	8.996E-01	9.019E-01	9.018E-01	9.018E-01	7.210E+00

Table 7-7. (continued).

Isotope	Half-life (years)	Lobe Northwest NW-L or NW-R (Ci per block)	Lobe Northeast NE-L or NE-R (Ci per block)	Lobe Southwest SW-L or SW-R (Ci per block)	Lobe Southeast SE-L or SE-R (Ci per block)	Total Inventory for Eight Blocks (Ci for eight blocks)
Pu-242	3.75E+05	6.343E-05	6.121E-05	6.124E-05	6.133E-05	4.944E-04
Pu-244	8.00E+07	4.378E-11	3.910E-11	3.915E-11	3.934E-11	3.227E-10
Am-241	4.33E+02	8.068E-03	8.122E-03	8.122E-03	8.119E-03	6.486E-02
Am-243	7.37E+03	6.186E-04	5.820E-04	5.825E-04	5.840E-04	4.734E-03
Cm-243	2.91E+01	2.532E-04	2.475E-04	2.476E-04	2.478E-04	1.992E-03
Cm-244	1.81E+01	1.591E-01	1.433E-01	1.435E-01	1.441E-01	1.180E+00
Cm-245	8.50E+03	8.564E-06	7.646E-06	7.657E-06	7.693E-06	6.312E-05
Cm-246	4.76E+03	8.400E-06	7.176E-06	7.190E-06	7.238E-06	6.001E-05
Cm-247	1.56E+07	2.957E-11	2.444E-11	2.450E-11	2.470E-11	2.064E-10
Cm-248	3.48E+05	1.579E-10	1.253E-10	1.256E-10	1.269E-10	1.071E-09
	TRU concentration (nCi/g) =	321.97	321.12	321.13	321.23	321.36
	Lobe MWd =	28,894	27,967	27,978	28,017	For 8 blocks
	Beryllium mass (g) =	81,420.00	81,420.00	81,420.00	81,420.00	651,360.00
	Metal volume (m^3) =	0.0440	0.0440	0.0440	0.0440	0.3521

CFR = *Code of Federal Regulations*
NE-L = northeast-left
NE-R = northeast-right
NW-L = northwest-left
NW-R = northwest-right
SE-L = southeast-left
SE-R = southeast-right
SW-L = southwest –left
SW-R = southwest-right
TRU = transuranic waste

Table 7-8. Inventory calculated with Oak Ridge Isotope GENeration and Depletion Code Version 2 at the decay time of September 15, 2001, for Advanced Test Reactor beryllium blocks located in Core 1.

Isotope	Half-life (years)	Lobe Northwest NW-L or NW-R (Ci per block)	Lobe Northeast NE-L or NE-R (Ci per block)	Lobe Southwest SW-L or SW-R (Ci per block)	Lobe Southeast SE-L or SE-R (Ci per block)	Total Inventory for Eight Blocks (Ci for eight blocks)
H-3	1.23E+01	4.173E+03	4.014E+03	4.016E+03	4.023E+03	3.245E+04
Be-10	1.60E+06	1.246E-01	1.206E-01	1.206E-01	1.208E-01	9.732E-01
C-14	5.73E+03	9.967E-01	9.650E-01	9.654E-01	9.667E-01	7.788E+00
Cl-36	3.01E+05	8.389E-03	8.134E-03	8.137E-03	8.147E-03	6.561E-02
Co-60	5.27E+00	3.796E+00	3.689E+00	3.691E+00	3.695E+00	2.974E+01
Ni-59	7.60E+04	2.095E-02	2.053E-02	2.054E-02	2.055E-02	1.651E-01
Ni-63	1.00E+02	3.105E+00	3.018E+00	3.019E+00	3.023E+00	2.433E+01
Sr-90	2.91E+01	1.786E-01	1.731E-01	1.731E-01	1.734E-01	1.396E+00
Nb-94	2.00E+04	2.252E-03	2.186E-03	2.187E-03	2.190E-03	1.763E-02
Tc-99	2.13E+05	1.295E-04	1.256E-04	1.256E-04	1.258E-04	1.013E-03
I-129	1.57E+07	9.515E-07	9.215E-07	9.219E-07	9.231E-07	7.436E-06
Cs-137	3.02E+01	5.888E-01	5.687E-01	5.690E-01	5.699E-01	4.593E+00
Eu-152	1.35E+01	8.104E-03	9.271E-03	9.255E-03	9.204E-03	7.167E-02
Eu-154	8.59E+00	2.564E-01	2.591E-01	2.591E-01	2.590E-01	2.067E+00
10 CFR 61 (2002) Sum-of-fractions rule for:						
C-14+Ni-59+Nb-94+Tc-99+I-129 =		0.542	0.526	0.526	0.527	0.530
C-14+Ni-59+Nb-94+Tc-99+I-129+ Pu-241 =		1.500	1.486	1.486	1.486	1.489
Ni-63+Sr-90+Cs-137 =		0.014	0.013	0.013	0.013	0.013
Pb-210	2.23E+01	2.925E-12	2.804E-12	2.805E-12	2.810E-12	2.269E-11
Ra-226	1.60E+03	6.296E-12	6.169E-12	6.171E-12	6.176E-12	4.962E-11
Ra-228	5.76E+00	3.424E-09	3.435E-09	3.435E-09	3.434E-09	2.746E-08
Ac-227	2.18E+01	1.857E-08	1.835E-08	1.836E-08	1.837E-08	1.473E-07
Th-228	1.91E+00	7.874E-06	7.536E-06	7.540E-06	7.554E-06	6.101E-05
Th-229	7.30E+03	2.306E-08	2.304E-08	2.304E-08	2.304E-08	1.844E-07
Th-230	7.54E+04	7.644E-10	7.502E-10	7.504E-10	7.510E-10	6.032E-09
Th-232	1.40E+10	3.532E-09	3.544E-09	3.544E-09	3.543E-09	2.833E-08
Pa-231	3.28E+04	2.959E-08	2.923E-08	2.923E-08	2.925E-08	2.346E-07
U-232	7.00E+01	7.660E-06	7.331E-06	7.335E-06	7.349E-06	5.935E-05
U-233	1.59E+05	7.739E-06	7.732E-06	7.732E-06	7.733E-06	6.187E-05
U-234	2.46E+05	2.389E-06	2.352E-06	2.352E-06	2.354E-06	1.889E-05
U-235	7.04E+08	4.870E-10	5.356E-10	5.349E-10	5.328E-10	4.181E-09
U-236	2.34E+07	1.492E-07	1.500E-07	1.500E-07	1.500E-07	1.198E-06
U-238	4.47E+09	6.797E-07	6.837E-07	6.837E-07	6.835E-07	5.461E-06
Np-237	2.14E+06	3.606E-07	3.587E-07	3.587E-07	3.588E-07	2.874E-06
Pu-238	8.77E+01	8.683E-03	8.606E-03	8.607E-03	8.611E-03	6.901E-02
Pu-239	2.41E+04	2.506E-03	2.520E-03	2.519E-03	2.519E-03	2.013E-02
Pu-240	6.56E+03	4.395E-03	4.379E-03	4.379E-03	4.380E-03	3.507E-02
Pu-241	1.44E+01	2.728E-01	2.735E-01	2.735E-01	2.734E-01	2.186E+00
Pu-242	3.75E+05	6.342E-05	6.121E-05	6.124E-05	6.133E-05	4.944E-04
Pu-244	8.00E+07	4.378E-11	3.910E-11	3.915E-11	3.934E-11	3.227E-10

Table 7-8. (continued).

Isotope	Half-life (years)	Lobe Northwest NW-L or NW-R (Ci per block)	Lobe Northeast NE-L or NE-R (Ci per block)	Lobe Southwest SW-L or SW-R (Ci per block)	Lobe Southeast SE-L or SE-R (Ci per block)	Total Inventory for Eight Blocks (Ci for eight blocks)
Am-241	4.33E+02	2.815E-02	2.825E-02	2.825E-02	2.824E-02	2.258E-01
Am-243	7.37E+03	6.171E-04	5.806E-04	5.811E-04	5.826E-04	4.723E-03
Cm-243	2.91E+01	1.386E-04	1.354E-04	1.355E-04	1.356E-04	1.090E-03
Cm-244	1.81E+01	6.159E-02	5.549E-02	5.556E-02	5.581E-02	4.569E-01
Cm-245	8.50E+03	8.547E-06	7.630E-06	7.641E-06	7.678E-06	6.299E-05
Cm-246	4.76E+03	8.370E-06	7.150E-06	7.164E-06	7.212E-06	5.979E-05
Cm-247	1.56E+07	2.957E-11	2.444E-11	2.450E-11	2.470E-11	2.064E-10
Cm-248	3.48E+05	1.580E-10	1.254E-10	1.257E-10	1.270E-10	1.072E-09
	TRU concentration (nCi/g) =	547.41	547.13	547.14	547.10	547.20
	Lobe MWd =	28,894	27,967	27,978	28,017	For 8 blocks
	Beryllium mass (g) =	81,420.00	81,420.00	81,420.00	81,420.00	651,360.00
	Metal volume (m^3) =	0.0440	0.0440	0.0440	0.0440	0.3521

CFR = *Code of Federal Regulations*
NE-L = northeast-left
NE-R = northeast-right
NW-L = northwest-left
NW-R = northwest-right
SE-L = southeast-left
SE-R = southeast-right
SW-L = southwest –left
SW-R = southwest-right
TRU = transuranic waste

Table 7-9. Inventory calculated with Oak Ridge Isotope GENeration and Depletion Code Version 2 at the estimated disposal date of June 1, 1977, for Advanced Test Reactor beryllium blocks located in Core 2.

		Lobe Northwest	Lobe Northeast	Lobe Southwest	Lobe Southeast	
Isotope	Half-life (years)	NW-L or NW-R (Ci per block)	NE-L or NE-R (Ci per block)	SW-L or SW-R (Ci per block)	SE-L or SE-R (Ci per block)	Total for Six Blocks (NW blocks excluded) (Ci for six blocks)
H-3	1.23E+01	2.783E+04	1.660E+04	2.758E+04	1.723E+04	1.228E+05
Be-10	1.60E+06	1.576E-01	1.018E-01	1.564E-01	1.050E-01	7.264E-01
C-14	5.73E+03	1.264E+00	8.189E-01	1.254E+00	8.441E-01	5.834E+00
Cl-36	3.01E+05	1.047E-02	6.926E-03	1.039E-02	7.131E-03	4.889E-02
Co-60	5.27E+00	2.126E+02	1.456E+02	2.113E+02	1.496E+02	1.013E+03
Ni-59	7.60E+04	2.399E-02	1.840E-02	2.389E-02	1.878E-02	1.221E-01
Ni-63	1.00E+02	4.729E+00	3.237E+00	4.698E+00	3.326E+00	2.252E+01
Sr-90	2.91E+01	4.467E-01	2.927E-01	4.434E-01	3.018E-01	2.076E+00
Nb-94	2.00E+04	2.784E-03	1.875E-03	2.765E-03	1.928E-03	1.314E-02
Tc-99	2.13E+05	1.606E-04	1.063E-04	1.595E-04	1.096E-04	7.509E-04
I-129	1.57E+07	1.192E-06	7.783E-07	1.184E-06	8.025E-07	5.529E-06
Cs-137	3.02E+01	1.470E+00	9.275E-01	1.458E+00	9.591E-01	6.689E+00
Eu-152	1.35E+01	1.179E-02	7.731E-02	1.228E-02	6.949E-02	3.182E-01
Eu-154	8.59E+00	2.160E+00	2.675E+00	2.175E+00	2.662E+00	1.502E+01
10 CFR 61 (2002) Sum-of-fractions rule for:						
C-14+Ni-59+Nb-94+Tc-99+I-129 =		0.679	0.449	0.674	0.462	0.528
C-14+Ni-59+Nb-94+Tc-99+I-129+ Pu-241 =		4.403	4.319	4.405	4.336	4.353
Ni-63+Sr-90+Cs-137 =		0.024	0.016	0.024	0.017	0.019
Pb-210	2.23E+01	4.493E-12	1.515E-12	4.410E-12	1.639E-12	1.513E-11
Ra-226	1.60E+03	2.541E-13	1.858E-13	2.528E-13	1.900E-13	1.257E-12
Ra-228	5.76E+00	1.256E-09	1.309E-09	1.257E-09	1.306E-09	7.744E-09
Ac-227	2.18E+01	1.860E-09	1.697E-09	1.859E-09	1.714E-09	1.054E-08
Th-228	1.91E+00	5.224E-06	2.967E-06	5.178E-06	3.099E-06	2.249E-05
Th-229	7.30E+03	1.832E-09	1.773E-09	1.831E-09	1.779E-09	1.077E-08
Th-230	7.54E+04	2.769E-10	2.039E-10	2.755E-10	2.086E-10	1.376E-09
Th-232	1.40E+10	3.437E-09	3.599E-09	3.441E-09	3.589E-09	2.126E-08
Pa-231	3.28E+04	3.180E-08	2.725E-08	3.174E-08	2.763E-08	1.732E-07
U-232	7.00E+01	1.364E-05	7.647E-06	1.351E-05	7.990E-06	5.829E-05
U-233	1.59E+05	7.545E-06	7.530E-06	7.548E-06	7.543E-06	4.524E-05
U-234	2.46E+05	1.852E-06	1.434E-06	1.844E-06	1.461E-06	9.478E-06
U-235	7.04E+08	2.187E-10	8.285E-10	2.221E-10	7.468E-10	3.595E-09
U-236	2.34E+07	1.383E-07	1.496E-07	1.386E-07	1.491E-07	8.746E-07
U-238	4.47E+09	6.476E-07	7.027E-07	6.488E-07	6.995E-07	4.102E-06
Np-237	2.14E+06	2.056E-07	1.728E-07	2.053E-07	1.759E-07	1.108E-06
Pu-238	8.77E+01	7.230E-03	6.537E-03	7.239E-03	6.661E-03	4.087E-02
Pu-239	2.41E+04	2.399E-03	2.585E-03	2.403E-03	2.574E-03	1.512E-02

Table 7-9. (continued).

Isotope	Half-life (years)	Lobe Northwest NW-L or NW-R (Ci per block)	Lobe Northeast NE-L or NE-R (Ci per block)	Lobe Southwest SW-L or SW-R (Ci per block)	Lobe Southeast SE-L or SE-R (Ci per block)	Total for Six Blocks (NW blocks excluded) (Ci for six blocks)
Pu-240	6.56E+03	3.901E-03	4.151E-03	3.907E-03	4.142E-03	2.440E-02
Pu-241	1.44E+01	1.061E+00	1.103E+00	1.063E+00	1.104E+00	6.540E+00
Pu-242	3.75E+05	7.907E-05	4.994E-05	7.857E-05	5.195E-05	3.609E-04
Pu-244	8.00E+07	1.035E-10	2.312E-11	1.010E-10	2.586E-11	3.000E-10
Am-241	4.33E+02	1.201E-03	1.653E-03	1.209E-03	1.628E-03	8.980E-03
Am-243	7.37E+03	9.101E-04	4.128E-04	8.999E-04	4.409E-04	3.507E-03
Cm-243	2.91E+01	3.038E-04	2.284E-04	3.032E-04	2.363E-04	1.536E-03
Cm-244	1.81E+01	3.758E-01	9.536E-02	3.678E-01	1.060E-01	1.138E+00
Cm-245	8.50E+03	1.833E-05	4.128E-06	1.791E-05	4.636E-06	5.335E-05
Cm-246	4.76E+03	2.482E-05	3.089E-06	2.399E-05	3.614E-06	6.139E-05
Cm-247	1.56E+07	1.100E-10	8.840E-12	1.056E-10	1.067E-11	2.502E-10
Cm-248	3.48E+05	7.868E-10	3.679E-11	7.473E-10	4.609E-11	1.660E-09
	TRU concentration (nCi/g) =	197.34	191.90	197.52	193.35	194.26
	Lobe MWd =	36,569	23,625	36,285	24,357	For 6 blocks
	Beryllium mass (g) =	81,420.00	81,420.00	81,420.00	81,420.00	488,520.00
	Metal volume (m^3) =	0.0440	0.0440	0.0440	0.0440	0.2641

CFR = *Code of Federal Regulations*
NE-L = northeast-left
NE-R = northeast-right
NW-L = northwest-left
NW-R = northwest-right
SE-L = southeast-left
SE-R = southeast-right
SW-L = southwest –left
SW-R = southwest-right
TRU = transuranic waste

Table 7-10. Inventory calculated with Oak Ridge Isotope GENeration and Depletion Code Version 2 at the decay time of September 15, 2001, for Advanced Test Reactor beryllium blocks located in Core 2.

Isotope	Half-life (years)	Lobe NW NW-L or NW-R (Ci per block)	Lobe NE NE-L or NE-R (Ci per block)	Lobe SW SW-L or SW-R (Ci per block)	Lobe SE SE-L or SE-R (Ci per block)	Total for Six Blocks (NW blocks excluded) (Ci for six blocks)
H-3	1.23E+01	7.118E+03	4.245E+03	7.055E+03	4.407E+03	3.141E+04
Be-10	1.60E+06	1.576E-01	1.018E-01	1.564E-01	1.050E-01	7.264E-01
C-14	5.73E+03	1.260E+00	8.165E-01	1.250E+00	8.417E-01	5.816E+00
Cl-36	3.01E+05	1.047E-02	6.926E-03	1.039E-02	7.131E-03	4.889E-02
Co-60	5.27E+00	8.711E+00	5.965E+00	8.654E+00	6.130E+00	4.150E+01
Ni-59	7.60E+04	2.398E-02	1.840E-02	2.388E-02	1.878E-02	1.221E-01
Ni-63	1.00E+02	3.938E+00	2.695E+00	3.912E+00	2.770E+00	1.875E+01
Sr-90	2.91E+01	2.506E-01	1.642E-01	2.487E-01	1.693E-01	1.164E+00
Nb-94	2.00E+04	2.781E-03	1.873E-03	2.762E-03	1.927E-03	1.312E-02
Tc-99	2.13E+05	1.606E-04	1.063E-04	1.595E-04	1.096E-04	7.509E-04
I-129	1.57E+07	1.194E-06	7.790E-07	1.185E-06	8.033E-07	5.534E-06
Cs-137	3.02E+01	8.387E-01	5.291E-01	8.321E-01	5.472E-01	3.817E+00
Eu-152	1.35E+01	3.448E-03	2.246E-02	3.592E-03	2.019E-02	9.247E-02
Eu-154	8.59E+00	3.319E-01	3.903E-01	3.336E-01	3.892E-01	2.226E+00
10 CFR 61 (2002) Sum-of-fractions rule for:						
C-14+Ni-59+Nb-94+Tc-99+I-129 =		0.678	0.448	0.673	0.461	0.527
C-14+Ni-59+Nb-94+Tc-99+I-129+ Pu-241 =		1.834	1.649	1.831	1.664	1.715
Ni-63+Sr-90+Cs-137 =		0.018	0.012	0.018	0.012	0.014
Pb-210	2.23E+01	3.618E-12	1.838E-12	3.572E-12	1.920E-12	1.466E-11
Ra-226	1.60E+03	5.534E-12	4.197E-12	5.509E-12	4.284E-12	2.798E-11
Ra-228	5.76E+00	3.261E-09	3.413E-09	3.264E-09	3.404E-09	2.016E-08
Ac-227	2.18E+01	1.798E-08	1.545E-08	1.795E-08	1.566E-08	9.812E-08
Th-228	1.91E+00	1.110E-05	6.224E-06	1.100E-05	6.503E-06	4.745E-05
Th-229	7.30E+03	1.972E-08	1.944E-08	1.972E-08	1.948E-08	1.173E-07
Th-230	7.54E+04	7.552E-10	5.833E-10	7.521E-10	5.950E-10	3.861E-09
Th-232	1.40E+10	3.437E-09	3.599E-09	3.441E-09	3.589E-09	2.126E-08
Pa-231	3.28E+04	3.179E-08	2.724E-08	3.173E-08	2.761E-08	1.732E-07
U-232	7.00E+01	1.080E-05	6.055E-06	1.070E-05	6.326E-06	4.616E-05
U-233	1.59E+05	7.808E-06	7.709E-06	7.809E-06	7.728E-06	4.649E-05
U-234	2.46E+05	2.503E-06	2.018E-06	2.496E-06	2.056E-06	1.314E-05
U-235	7.04E+08	2.761E-10	8.903E-10	2.795E-10	8.083E-10	3.956E-09
U-236	2.34E+07	1.414E-07	1.526E-07	1.416E-07	1.521E-07	8.926E-07
U-238	4.47E+09	6.476E-07	7.027E-07	6.488E-07	6.995E-07	4.102E-06
Np-237	2.14E+06	3.276E-07	3.027E-07	3.275E-07	3.057E-07	1.872E-06
Pu-238	8.77E+01	8.579E-03	7.704E-03	8.586E-03	7.850E-03	4.828E-02
Pu-239	2.41E+04	2.399E-03	2.583E-03	2.402E-03	2.573E-03	1.512E-02
Pu-240	6.56E+03	4.520E-03	4.300E-03	4.513E-03	4.309E-03	2.624E-02
Pu-241	1.44E+01	3.296E-01	3.425E-01	3.301E-01	3.428E-01	2.031E+00
Pu-242	3.75E+05	7.907E-05	4.994E-05	7.857E-05	5.195E-05	3.609E-04

Table 7-10. (continued).

Isotope	Half-life (years)	Lobe NW NW-L or NW-R (Ci per block)	Lobe NE NE-L or NE-R (Ci per block)	Lobe SW SW-L or SW-R (Ci per block)	Lobe SE SE-L or SE-R (Ci per block)	Total for Six Blocks (NW blocks excluded) (Ci for six blocks)
Pu-244	8.00E+07	1.035E-10	2.312E-11	1.010E-10	2.586E-11	3.000E-10
Am-241	4.33E+02	2.497E-02	2.634E-02	2.501E-02	2.634E-02	1.554E-01
Am-243	7.37E+03	9.080E-04	4.119E-04	8.978E-04	4.399E-04	3.499E-03
Cm-243	2.91E+01	1.683E-04	1.265E-04	1.680E-04	1.309E-04	8.508E-04
Cm-244	1.81E+01	1.483E-01	3.764E-02	1.451E-01	4.185E-02	4.492E-01
Cm-245	8.50E+03	1.829E-05	4.119E-06	1.787E-05	4.627E-06	5.323E-05
Cm-246	4.76E+03	2.474E-05	3.078E-06	2.391E-05	3.601E-06	6.118E-05
Cm-247	1.56E+07	1.100E-10	8.840E-12	1.056E-10	1.067E-11	2.502E-10
Cm-248	3.48E+05	7.906E-10	3.685E-11	7.508E-10	4.617E-11	1.668E-09
Transuranic concentration (nCi/g) =		511.75	509.98	512.13	512.20	511.44
Lobe MWd =		36,569	23,625	36,285	24,357	For 6 blocks
Beryllium mass (g) =		81,420.00	81,420.00	81,420.00	81,420.00	488,520.00
Metal volume (m^3) =		0.0440	0.0440	0.0440	0.0440	0.2641

CFR = *Code of Federal Regulations*
NE-L = northeast-left
NE-R = northeast-right
NW-L = northwest-left
NW-R = northwest-right
SE-L = southeast-left
SE-R = southeast-right
SW-L = southwest –left
SW-R = southwest-right
TRU = transuranic waste

Table 7-11. Inventory calculated with Oak Ridge Isotope GENeration and Depletion Code Version 2 at the estimated disposal date of July 1, 1993, for Advanced Test Reactor beryllium blocks located in Core 3.

Isotope	Half-life (years)	NW-L or NW-R 018L & 013R (Ci per block)	NE-L or NE-R 015L (Ci per block)	SW-L or SW-R 019L & 014R (Ci per block)	SE-L or SE-R 011R (Ci per block)	Total for Six Blocks (Ci for six blocks)
H-3	1.23E+01	2.796E+04	2.416E+04	3.155E+04	3.885E+04	1.820E+05
Be-10	1.60E+06	2.324E-01	2.037E-01	2.595E-01	3.145E-01	1.502E+00
C-14	5.73E+03	1.853E+00	1.627E+00	2.066E+00	2.497E+00	1.196E+01
Cl-36	3.01E+05	1.496E-02	1.327E-02	1.652E-02	1.957E-02	9.580E-02
Co-60	5.27E+00	8.579E+01	7.760E+01	9.299E+01	1.062E+02	5.414E+02
Ni-59	7.60E+04	2.856E-02	2.711E-02	2.964E-02	3.120E-02	1.747E-01
Ni-63	1.00E+02	6.017E+00	5.431E+00	6.535E+00	7.492E+00	3.803E+01
Sr-90	2.91E+01	5.080E-01	4.521E-01	5.587E-01	6.561E-01	3.242E+00
Nb-94	2.00E+04	3.884E-03	3.476E-03	4.251E-03	4.952E-03	2.470E-02
Tc-99	2.13E+05	2.166E-04	1.966E-04	2.335E-04	2.625E-04	1.359E-03
I-129	1.57E+07	1.701E-06	1.512E-06	1.872E-06	2.201E-06	1.086E-05
Cs-137	3.02E+01	1.727E+00	1.525E+00	1.911E+00	2.269E+00	1.107E+01
Eu-152	1.35E+01	7.283E-04	1.608E-03	3.969E-04	1.911E-04	4.049E-03
Eu-154	8.59E+00	8.311E-01	9.597E-01	7.288E-01	5.760E-01	4.656E+00
10 CFR 61 (2002) Sum-of-fractions rule for:						
	C-14+Ni-59+Nb-94+Tc-99+I-129 =	0.973	0.862	1.075	1.278	1.039
	C-14+Ni-59+Nb-94+Tc-99+I-129+ Pu-241 =	3.349	3.324	3.371	3.415	3.363
	Ni-63+Sr-90+Cs-137 =	0.030	0.027	0.032	0.038	0.031
Pb-210	2.23E+01	8.750E-12	6.607E-12	1.099E-11	1.607E-11	6.216E-11
Ra-226	1.60E+03	2.421E-12	2.260E-12	2.552E-12	2.771E-12	1.498E-11
Ra-228	5.76E+00	2.626E-09	2.687E-09	2.571E-09	2.461E-09	1.554E-08
Ac-227	2.18E+01	9.579E-09	9.603E-09	9.476E-09	9.125E-09	5.684E-08
Th-228	1.91E+00	1.869E-05	1.651E-05	2.049E-05	2.342E-05	1.183E-04
Th-229	7.30E+03	8.473E-09	8.543E-09	8.413E-09	8.306E-09	5.062E-08
Th-230	7.54E+04	5.909E-10	5.561E-10	6.189E-10	6.644E-10	3.640E-09
Th-232	1.40E+10	3.232E-09	3.310E-09	3.161E-09	3.021E-09	1.912E-08
Pa-231	3.28E+04	3.354E-08	3.326E-08	3.353E-08	3.297E-08	2.004E-07
U-232	7.00E+01	1.886E-05	1.665E-05	2.069E-05	2.366E-05	1.194E-04
U-233	1.59E+05	7.177E-06	7.279E-06	7.079E-06	6.879E-06	4.267E-05
U-234	2.46E+05	2.226E-06	2.176E-06	2.259E-06	2.295E-06	1.344E-05
U-235	7.04E+08	1.699E-10	1.724E-10	1.718E-10	1.770E-10	1.033E-09
U-236	2.34E+07	1.230E-07	1.291E-07	1.175E-07	1.074E-07	7.175E-07
U-238	4.47E+09	5.805E-07	6.054E-07	5.579E-07	5.147E-07	3.397E-06
Np-237	2.14E+06	2.252E-07	2.291E-07	2.194E-07	2.048E-07	1.323E-06
Pu-238	8.77E+01	1.246E-02	1.360E-02	1.146E-02	9.733E-03	7.117E-02
Pu-239	2.41E+04	2.147E-03	2.237E-03	2.066E-03	1.910E-03	1.257E-02

Table 7-11. (continued).

Isotope	Half-life (years)	NW-L or NW-R 018L & 013R (Ci per block)	NE-L or NE-R 015L (Ci per block)	SW-L or SW-R 019L & 014R (Ci per block)	SE-L or SE-R 011R (Ci per block)	Total for Six Blocks (Ci for six blocks)
Pu-240	6.56E+03	4.184E-03	4.162E-03	4.213E-03	4.281E-03	2.524E-02
Pu-241	1.44E+01	6.773E-01	7.018E-01	6.544E-01	6.090E-01	3.974E+00
Pu-242	3.75E+05	9.953E-05	9.354E-05	1.034E-04	1.072E-04	6.066E-04
Pu-244	8.00E+07	1.841E-10	1.276E-10	2.464E-10	3.983E-10	1.387E-09
Am-241	4.33E+02	1.081E-02	1.137E-02	1.032E-02	9.437E-03	6.307E-02
Am-243	7.37E+03	1.396E-03	1.239E-03	1.509E-03	1.654E-03	8.703E-03
Cm-243	2.91E+01	2.624E-04	2.703E-04	2.536E-04	2.351E-04	1.537E-03
Cm-244	1.81E+01	7.037E-01	5.259E-01	8.768E-01	1.224E+00	4.911E+00
Cm-245	8.50E+03	4.842E-05	3.553E-05	6.113E-05	8.688E-05	3.415E-04
Cm-246	4.76E+03	1.143E-04	6.949E-05	1.691E-04	3.180E-04	9.543E-04
Cm-247	1.56E+07	7.205E-10	3.916E-10	1.164E-09	2.522E-09	6.683E-09
Cm-248	3.48E+05	8.563E-09	3.919E-09	1.599E-08	4.482E-08	9.785E-08
TRU concentration (nCi/g) =		387.15	406.25	370.37	340.98	377.05
Lobe MWd =		53,924	47,259	60,205	72,984	For 6 blocks
Beryllium mass (g) =		81,420.00	81,420.00	81,420.00	81,420.00	488,520.00
Metal volume (m^3) =		0.0440	0.0440	0.0440	0.0440	0.2641

CFR = *Code of Federal Regulations*
NW-L = northwest-left
SE-R = southeast-right
TRU = transuranic waste
NE-L = northeast-left
NW-R = northwest-right
SW-L = southwest –left
NE-R = northeast-right
SE-L = southeast-left
SW-R = southwest-right

Table 7-12. Inventory calculated with Oak Ridge Isotope GENeration and Depletion Code Version 2 at the decay time of September 15, 2001, for Advanced Test Reactor beryllium blocks located in Core 3.

Isotope	Half-life (years)	NW-L or NW-R 018L and 013R (Ci per block)	NE-L or NE-R 015L (Ci per block)	SW-L or SW-R 019L & 014R (Ci per block)	SE-L or SE-R 011R (Ci per block)	Total for Six Blocks (Ci for six blocks)
H-3	1.23E+01	1.764E+04	1.524E+04	1.990E+04	2.451E+04	1.148E+05
Be-10	1.60E+06	2.324E-01	2.037E-01	2.595E-01	3.145E-01	1.502E+00
C-14	5.73E+03	1.851E+00	1.625E+00	2.064E+00	2.494E+00	1.195E+01
Cl-36	3.01E+05	1.496E-02	1.327E-02	1.652E-02	1.957E-02	9.580E-02
Co-60	5.27E+00	2.914E+01	2.636E+01	3.159E+01	3.608E+01	1.839E+02
Ni-59	7.60E+04	2.856E-02	2.711E-02	2.964E-02	3.119E-02	1.747E-01
Ni-63	1.00E+02	5.657E+00	5.105E+00	6.143E+00	7.043E+00	3.575E+01
Sr-90	2.91E+01	4.178E-01	3.719E-01	4.595E-01	5.396E-01	2.666E+00
Nb-94	2.00E+04	3.883E-03	3.475E-03	4.250E-03	4.951E-03	2.469E-02
Tc-99	2.13E+05	2.166E-04	1.966E-04	2.335E-04	2.625E-04	1.359E-03
I-129	1.57E+07	1.701E-06	1.512E-06	1.872E-06	2.201E-06	1.086E-05
Cs-137	3.02E+01	1.429E+00	1.262E+00	1.581E+00	1.877E+00	9.158E+00
Eu-152	1.35E+01	4.793E-04	1.058E-03	2.613E-04	1.258E-04	2.665E-03
Eu-154	8.59E+00	4.289E-01	4.953E-01	3.761E-01	2.972E-01	2.402E+00
10 CFR 61 (2002) Sum-of-fractions rule for:						
C-14+Ni-59+Nb-94+Tc-99+I-129 =		0.972	0.861	1.074	1.277	1.038
C-14+Ni-59+Nb-94+Tc-99+I-129+ Pu-241 =		2.573	2.520	2.621	2.716	2.604
Ni-63+Sr-90+Cs-137 =		0.027	0.024	0.029	0.034	0.028
Pb-210	2.23E+01	7.593E-12	5.882E-12	9.367E-12	1.337E-11	5.317E-11
Ra-226	1.60E+03	4.814E-12	4.525E-12	5.048E-12	5.431E-12	2.968E-11
Ra-228	5.76E+00	2.973E-09	3.043E-09	2.909E-09	2.782E-09	1.759E-08
Ac-227	2.18E+01	1.509E-08	1.504E-08	1.501E-08	1.461E-08	8.985E-08
Th-228	1.91E+00	1.787E-05	1.578E-05	1.960E-05	2.242E-05	1.131E-04
Th-229	7.30E+03	1.403E-08	1.418E-08	1.389E-08	1.363E-08	8.365E-08
Th-230	7.54E+04	7.658E-10	7.283E-10	7.954E-10	8.421E-10	4.693E-09
Th-232	1.40E+10	3.232E-09	3.310E-09	3.161E-09	3.021E-09	1.912E-08
Pa-231	3.28E+04	3.354E-08	3.325E-08	3.352E-08	3.297E-08	2.003E-07
U-232	7.00E+01	1.743E-05	1.539E-05	1.912E-05	2.187E-05	1.104E-04
U-233	1.59E+05	7.177E-06	7.279E-06	7.079E-06	6.879E-06	4.267E-05
U-234	2.46E+05	2.507E-06	2.482E-06	2.517E-06	2.514E-06	1.504E-05
U-235	7.04E+08	1.872E-10	1.905E-10	1.885E-10	1.924E-10	1.134E-09
U-236	2.34E+07	1.241E-07	1.301E-07	1.186E-07	1.085E-07	7.240E-07
U-238	4.47E+09	5.805E-07	6.054E-07	5.579E-07	5.147E-07	3.397E-06
Np-237	2.14E+06	2.641E-07	2.700E-07	2.567E-07	2.391E-07	1.551E-06
Pu-238	8.77E+01	1.168E-02	1.275E-02	1.074E-02	9.123E-03	6.671E-02
Pu-239	2.41E+04	2.147E-03	2.237E-03	2.066E-03	1.910E-03	1.257E-02
Pu-240	6.56E+03	4.705E-03	4.551E-03	4.864E-03	5.190E-03	2.888E-02

Table 7-12. (continued).

Isotope	Half-life (years)	NW-L or NW-R 018L and 013R (Ci per block)	NE-L or NE-R 015L (Ci per block)	SW-L or SW-R 019L & 014R (Ci per block)	SE-L or SE-R 011R (Ci per block)	Total for Six Blocks (Ci for six blocks)
Pu-241	1.44E+01	4.562E-01	4.727E-01	4.408E-01	4.102E-01	2.677E+00
Pu-242	3.75E+05	9.953E-05	9.354E-05	1.034E-04	1.072E-04	6.066E-04
Pu-244	8.00E+07	1.841E-10	1.276E-10	2.464E-10	3.983E-10	1.387E-09
Am-241	4.33E+02	1.798E-02	1.880E-02	1.725E-02	1.589E-02	1.052E-01
Am-243	7.37E+03	1.395E-03	1.238E-03	1.508E-03	1.653E-03	8.697E-03
Cm-243	2.91E+01	2.149E-04	2.214E-04	2.077E-04	1.925E-04	1.259E-03
Cm-244	1.81E+01	5.139E-01	3.841E-01	6.404E-01	8.937E-01	3.586E+00
Cm-245	8.50E+03	4.839E-05	3.551E-05	6.108E-05	8.682E-05	3.413E-04
Cm-246	4.76E+03	1.142E-04	6.940E-05	1.689E-04	3.176E-04	9.532E-04
Cm-247	1.56E+07	7.205E-10	3.916E-10	1.164E-09	2.522E-09	6.683E-09
Cm-248	3.48E+05	8.572E-09	3.922E-09	1.601E-08	4.491E-08	9.800E-08
	TRU concentration (nCi/g) =	471.44	491.23	454.06	423.37	460.93
	Lobe MWd =	53,924	47,259	60,205	72,984	For 6 blocks
	Beryllium mass (g) =	81,420.00	81,420.00	81,420.00	81,420.00	488,520.00
	Metal volume (m^3) =	0.0440	0.0440	0.0440	0.0440	0.2641

CFR = *Code of Federal Regulations*
NE-L = northeast-left
NE-R = northeast-right
NW-L = northwest-left
NW-R = northwest-right
SE-L = southeast-left
SE-R = southeast-right
SW-L = southwest –left
SW-R = southwest-right
TRU = transuranic waste

Table 7-13. Inventory calculated with Oak Ridge Isotope GENeration and Depletion Code Version 2 at the estimated disposal date of September 1, 1987, for the outer shim control cylinders located in Cores 1 and 2.

Isotope	Half-life (years)	Total Inventory for 16 OSCCs (Ci per 16 OSCCs)	Inventory for Nine of the 16 OSCCs (Ci per nine OSCCs)
H-3	1.23E+01	1.532E+05	8.615E+04
Be-10	1.60E+06	3.574E+00	2.010E+00
C-14	5.73E+03	2.833E+01	1.593E+01
Cl-36	3.01E+05	1.718E-01	9.663E-02
Co-60	5.27E+00	7.379E+02	4.151E+02
Ni-59	7.60E+04	3.447E-01	1.939E-01
Ni-63	1.00E+02	8.133E+01	4.575E+01
Sr-90	2.91E+01	5.333E+00	3.000E+00
Nb-94	2.00E+04	4.981E-02	2.802E-02
Tc-99	2.13E+05	2.402E-03	1.351E-03
I-129	1.57E+07	1.937E-05	1.089E-05
Cs-137	3.02E+01	1.825E+01	1.026E+01
Eu-152	1.35E+01	5.292E-03	2.976E-03
Eu-154	8.59E+00	6.391E+00	3.595E+00
10 CFR 61 (2002) Sum-of-fractions rule for:			
	C-14+Ni-59+Nb-94+Tc-99+I-129 =	1.287	1.287
	C-14+Ni-59+Nb-94+Tc-99+I-129+Pu-241 =	2.747	2.747
	Ni-63+Sr-90+Cs-137 =	0.035	0.035
Pb-210	2.23E+01	6.196E-11	3.485E-11
Ra-226	1.60E+03	2.722E-11	1.531E-11
Ra-228	5.76E+00	2.903E-08	1.633E-08
Ac-227	2.18E+01	7.230E-08	4.067E-08
Th-228	1.91E+00	1.226E-04	6.896E-05
Th-229	7.30E+03	9.479E-08	5.332E-08
Th-230	7.54E+04	5.659E-09	3.183E-09
Th-232	1.40E+10	3.316E-08	1.865E-08
Pa-231	3.28E+04	2.063E-07	1.161E-07
U-232	7.00E+01	1.208E-04	6.797E-05
U-233	1.59E+05	6.629E-05	3.729E-05
U-234	2.46E+05	2.230E-05	1.254E-05

Table 7-13. (continued).

Isotope	Half-life (years)	Total Inventory for 16 OSCCs (Ci per 16 OSCCs)	Inventory for Nine of the 16 OSCCs (Ci per nine OSCCs)
U-235	7.04E+08	1.584E-09	8.911E-10
U-236	2.34E+07	1.255E-06	7.062E-07
U-238	4.47E+09	6.124E-06	3.445E-06
Np-237	2.14E+06	1.865E-06	1.049E-06
Pu-238	8.77E+01	7.606E-02	4.278E-02
Pu-239	2.41E+04	1.718E-02	9.665E-03
Pu-240	6.56E+03	4.388E-02	2.468E-02
Pu-241	1.44E+01	4.450E+00	2.503E+00
Pu-242	3.75E+05	1.055E-03	5.935E-04
Pu-244	8.00E+07	3.086E-09	1.736E-09
Am-241	4.33E+02	1.021E-01	5.743E-02
Am-243	7.37E+03	1.455E-02	8.185E-03
Cm-243	2.91E+01	1.604E-03	9.025E-04
Cm-244	1.81E+01	7.841E+00	4.411E+00
Cm-245	8.50E+03	4.597E-04	2.586E-04
Cm-246	4.76E+03	1.771E-03	9.961E-04
Cm-247	1.56E+07	1.100E-08	6.186E-09
Cm-248	3.48E+05	2.003E-07	1.127E-07
	Transuranic concentration (nCi/g) =	297.01	297.01
		Total for 16 OSCCs	Total for Nine OSCCs
	Beryllium mass (g) =	870,900	489,880
	Metal volume (m^3) =	0.4708	0.2648

CFR = *Code of Federal Regulations* OSCC = outer shim control cylinder

Table 7-14. Inventory calculated with Oak Ridge Isotope GENeration and Depletion Code Version 2 at the decay time of September 15, 2001, for the outer shim control cylinders located in Cores 1 and 2.

Isotope	Half-life (years)	Total Inventory for 16 OSCCs (Ci per 16 OSCCs)	Inventory for Nine of the 16 OSCCs (Ci per Nine OSCCs)
H-3	1.23E+01	6.964E+04	3.917E+04
Be-10	1.60E+06	3.574E+00	2.010E+00
C-14	5.73E+03	2.828E+01	1.591E+01
Cl-36	3.01E+05	1.718E-01	9.663E-02
Co-60	5.27E+00	1.164E+02	6.548E+01
Ni-59	7.60E+04	3.446E-01	1.938E-01
Ni-63	1.00E+02	7.316E+01	4.115E+01
Sr-90	2.91E+01	3.817E+00	2.147E+00
Nb-94	2.00E+04	4.979E-02	2.801E-02
Tc-99	2.13E+05	2.402E-03	1.351E-03
I-129	1.57E+07	1.937E-05	1.089E-05
Cs-137	3.02E+01	1.319E+01	7.419E+00
Eu-152	1.35E+01	2.587E-03	1.455E-03
Eu-154	8.59E+00	2.061E+00	1.159E+00
10 CFR 61 (2002) Sum-of-fractions rule for:			
C-14+Ni-59+Nb-94+Tc-99+I-129 =		1.285	1.285
C-14+Ni-59+Nb-94+Tc-99+I-129+Pu-241 =		2.028	2.028
Ni-63+Sr-90+Cs-137 =		0.029	0.029
Pb-210	2.23E+01	5.729E-11	3.223E-11
Ra-226	1.60E+03	7.031E-11	3.955E-11
Ra-228	5.76E+00	3.219E-08	1.811E-08
Ac-227	2.18E+01	1.206E-07	6.784E-08
Th-228	1.91E+00	1.085E-04	6.101E-05
Th-229	7.30E+03	1.825E-07	1.027E-07
Th-230	7.54E+04	8.662E-09	4.872E-09
Th-232	1.40E+10	3.316E-08	1.865E-08
Pa-231	3.28E+04	2.063E-07	1.160E-07
U-232	7.00E+01	1.056E-04	5.938E-05
U-233	1.59E+05	6.628E-05	3.728E-05
U-234	2.46E+05	2.517E-05	1.416E-05
U-235	7.04E+08	1.822E-09	1.025E-09
U-236	2.34E+07	1.276E-06	7.175E-07
U-238	4.47E+09	6.124E-06	3.445E-06
Np-237	2.14E+06	2.507E-06	1.410E-06
Pu-238	8.77E+01	6.809E-02	3.830E-02
Pu-239	2.41E+04	1.718E-02	9.665E-03
Pu-240	6.56E+03	5.284E-02	2.972E-02
Pu-241	1.44E+01	2.264E+00	1.273E+00
Pu-242	3.75E+05	1.055E-03	5.936E-04
Pu-244	8.00E+07	3.086E-09	1.736E-09

Table 7-14. (continued).

Isotope	Half-life (years)	Total Inventory for 16 OSCCs (Ci per 16 OSCCs)	Inventory for Nine of the 16 OSCCs (Ci per Nine OSCCs)
Am-241	4.33E+02	1.717E-01	9.660E-02
Am-243	7.37E+03	1.453E-02	8.174E-03
Cm-243	2.91E+01	1.140E-03	6.415E-04
Cm-244	1.81E+01	4.582E+00	2.577E+00
Cm-245	8.50E+03	4.591E-04	2.583E-04
Cm-246	4.76E+03	1.767E-03	9.941E-04
Cm-247	1.56E+07	1.100E-08	6.186E-09
Cm-248	3.48E+05	2.005E-07	1.128E-07
	Transuranic concentration (nCi/g) =	377.54	377.54
		Total for 16 OSCCs	Total for Nine OSCCs
	Beryllium mass (g) =	870,899	489,880
	Metal volume (m^3) =	0.4708	0.2648

CFR = *Code of Federal Regulations* OSCC = outer shim control cylinder

Table 7-15. Data computed with Oak Ridge Isotope GENeration and Depletion Code Version 2 at the time of disposal for Advanced Test Reactor beryllium.

Isotope	Half-life (years)	12/01/76 Eight Buried Blocks from Core 1 (Ci for eight blocks)	06/01/77 Six Buried Blocks from Core 2 (Ci for six blocks)	07/01/93 Six Buried Blocks from Core 3 (Ci for six blocks)	09/01/87 Nine of the 16 OSCCs from Cores 1 and 2 (Ci per nine OSCCs)	Total Inventory for 20 Blocks and Nine OSCCs (Ci total)
H-3	1.23E+01	1.305E+05	1.228E+05	1.820E+05	8.615E+04	5.215E+05
Be-10	1.60E+06	9.732E-01	7.264E-01	1.502E+00	2.010E+00	5.212E+00
C-14	5.73E+03	7.811E+00	5.834E+00	1.196E+01	1.593E+01	4.154E+01
Cl-36	3.01E+05	6.562E-02	4.889E-02	9.580E-02	9.663E-02	3.069E-01
Co-60	5.27E+00	7.752E+02	1.013E+03	5.414E+02	4.151E+02	2.745E+03
Ni-59	7.60E+04	1.652E-01	1.221E-01	1.747E-01	1.939E-01	6.559E-01
Ni-63	1.00E+02	2.933E+01	2.252E+01	3.803E+01	4.575E+01	1.356E+02
Sr-90	2.91E+01	2.519E+00	2.076E+00	3.242E+00	3.000E+00	1.084E+01
Nb-94	2.00E+04	1.765E-02	1.314E-02	2.470E-02	2.802E-02	8.350E-02
Tc-99	2.13E+05	1.013E-03	7.509E-04	1.359E-03	1.351E-03	4.475E-03
I-129	1.57E+07	7.436E-06	5.529E-06	1.086E-05	1.089E-05	3.472E-05
Cs-137	3.02E+01	8.143E+00	6.689E+00	1.107E+01	1.026E+01	3.617E+01
Eu-152	1.35E+01	2.535E-01	3.189E-01	4.049E-03	2.976E-03	5.794E-01
Eu-154	8.59E+00	1.524E+01	1.577E+01	4.656E+00	3.595E+00	3.926E+01
10 CFR 61 (2002) Sum-of-fractions rule for:						
C-14+Ni-59+Nb-94+Tc-99+I-129 =		0.531	0.528	1.039	1.287	0.822
C-14+Ni-59+Nb-94+Tc-99+I-129+ Pu-241 =		3.694	4.353	3.363	2.747	3.551
Ni-63+Sr-90+Cs-137 =		0.018	0.019	0.031	0.035	0.025
Pb-210	2.23E+01	1.742E-11	1.513E-11	6.216E-11	3.485E-11	1.296E-10
Ra-226	1.60E+03	5.705E-12	1.257E-12	1.498E-11	1.531E-11	3.725E-11
Ra-228	5.76E+00	1.705E-08	7.744E-09	1.554E-08	1.633E-08	5.666E-08
Ac-227	2.18E+01	4.235E-08	1.054E-08	5.684E-08	4.067E-08	1.504E-07
Th-228	1.91E+00	6.640E-05	2.249E-05	1.183E-04	6.896E-05	2.761E-04
Th-229	7.30E+03	3.977E-08	1.077E-08	5.062E-08	5.332E-08	1.545E-07
Th-230	7.54E+04	2.394E-09	1.376E-09	3.640E-09	3.183E-09	1.059E-08
Th-232	1.40E+10	2.833E-08	2.126E-08	1.912E-08	1.865E-08	8.735E-08
Pa-231	3.28E+04	2.347E-07	1.732E-07	2.004E-07	1.161E-07	7.244E-07
U-232	7.00E+01	7.534E-05	5.829E-05	1.194E-04	6.797E-05	3.210E-04
U-233	1.59E+05	6.188E-05	4.524E-05	4.267E-05	3.729E-05	1.871E-04
U-234	2.46E+05	1.354E-05	9.478E-06	1.344E-05	1.254E-05	4.900E-05
U-235	7.04E+08	3.689E-09	3.595E-09	1.033E-09	8.911E-10	9.207E-09
U-236	2.34E+07	1.173E-06	8.746E-07	7.175E-07	7.062E-07	3.472E-06
U-238	4.47E+09	5.461E-06	4.102E-06	3.397E-06	3.445E-06	1.640E-05
Np-237	2.14E+06	1.571E-06	1.108E-06	1.323E-06	1.049E-06	5.051E-06
Pu-238	8.77E+01	8.382E-02	4.087E-02	7.117E-02	4.278E-02	2.387E-01

Table 7-15. (continued).

Isotope	Half-life (years)	12/01/76 Eight Buried Blocks from Core 1 (Ci for eight blocks)	06/01/77 Six Buried Blocks from Core 2 (Ci for six blocks)	07/01/93 Six Buried Blocks from Core 3 (Ci for six blocks)	09/01/87 Nine of the 16 OSCCs from Cores 1 and 2 (Ci per nine OSCCs)	Total Inventory for 20 Blocks and Nine OSCCs (Ci total)
Pu-239	2.41E+04	2.014E-02	1.512E-02	1.257E-02	9.665E-03	5.750E-02
Pu-240	6.56E+03	3.316E-02	2.440E-02	2.524E-02	2.468E-02	1.075E-01
Pu-241	1.44E+01	7.210E+00	6.540E+00	3.974E+00	2.503E+00	2.023E+01
Pu-242	3.75E+05	4.944E-04	3.609E-04	6.066E-04	5.935E-04	2.055E-03
Pu-244	8.00E+07	3.227E-10	3.000E-10	1.387E-09	1.736E-09	3.745E-09
Am-241	4.33E+02	6.486E-02	8.980E-03	6.307E-02	5.743E-02	1.943E-01
Am-243	7.37E+03	4.734E-03	3.507E-03	8.703E-03	8.185E-03	2.513E-02
Cm-243	2.91E+01	1.992E-03	1.536E-03	1.537E-03	9.025E-04	5.968E-03
Cm-244	1.81E+01	1.180E+00	1.138E+00	4.911E+00	4.411E+00	1.164E+01
Cm-245	8.50E+03	6.312E-05	5.335E-05	3.415E-04	2.586E-04	7.166E-04
Cm-246	4.76E+03	6.001E-05	6.139E-05	9.543E-04	9.961E-04	2.072E-03
Cm-247	1.56E+07	2.064E-10	2.502E-10	6.683E-09	6.186E-09	1.333E-08
Cm-248	3.48E+05	1.071E-09	1.660E-09	9.785E-08	1.127E-07	2.133E-07
Average transuranic concentration (nCi/g) =		321.36	194.26	377.05	297.01	299.26
Beryllium mass (g) =		651,360	488,520	488,520	489,881	2,118,281
Metal volume (m^3) =		0.352	0.264	0.264	0.265	1.145

CFR = *Code of Federal Regulations* OSCC = outer shim control cylinder

Table 7-16. Data computed with Oak Ridge Isotope GENeration and Depletion Code Version 2 at the decay time of September 15, 2001, for disposal of Advanced Test Reactor beryllium.

Isotope	Half-life (years)	09/15/01 Eight Buried Blocks from Core 1 (Ci for eight blocks)	09/15/01 Six Buried Blocks from Core 2 (Ci for six blocks)	09/15/01 Six Buried Blocks from Core 3 (Ci for six blocks)	09/15/01 Nine of the 16 OSCCs from Cores 1 and 2 (Ci per nine OSCCs)	Total Inventory for 20 Blocks and Nine OSCCs (Ci total)
H-3	1.23E+01	3.245E+04	3.141E+04	1.148E+05	3.917E+04	2.179E+05
Be-10	1.60E+06	9.732E-01	7.264E-01	1.502E+00	2.010E+00	5.212E+00
C-14	5.73E+03	7.788E+00	5.816E+00	1.195E+01	1.591E+01	4.146E+01
Cl-36	3.01E+05	6.561E-02	4.889E-02	9.580E-02	9.663E-02	3.069E-01
Co-60	5.27E+00	2.974E+01	4.150E+01	1.839E+02	6.548E+01	3.206E+02
Ni-59	7.60E+04	1.651E-01	1.221E-01	1.747E-01	1.938E-01	6.558E-01
Ni-63	1.00E+02	2.433E+01	1.875E+01	3.575E+01	4.115E+01	1.200E+02
Sr-90	2.91E+01	1.396E+00	1.164E+00	2.666E+00	2.147E+00	7.374E+00
Nb-94	2.00E+04	1.763E-02	1.312E-02	2.469E-02	2.801E-02	8.345E-02
Tc-99	2.13E+05	1.013E-03	7.509E-04	1.359E-03	1.351E-03	4.475E-03
I-129	1.57E+07	7.436E-06	5.534E-06	1.086E-05	1.089E-05	3.472E-05
Cs-137	3.02E+01	4.593E+00	3.817E+00	9.158E+00	7.419E+00	2.499E+01
Eu-152	1.35E+01	7.167E-02	9.247E-02	2.665E-03	1.455E-03	1.683E-01
Eu-154	8.59E+00	2.067E+00	2.226E+00	2.402E+00	1.159E+00	7.855E+00
10 CFR 61 (2002) Sum-of-fractions rule for:						
C-14+Ni-59+Nb-94+Tc-99+ I-129 =		0.530	0.527	1.038	1.285	0.821
C-14+Ni-59+Nb-94+Tc-99+I-129+Pu-241 =		1.489	1.715	2.604	2.028	1.923
Ni-63+Sr-90+Cs-137 =		0.013	0.014	0.028	0.029	0.021
Pb-210	2.23E+01	2.269E-11	1.466E-11	5.317E-11	3.223E-11	1.227E-10
Ra-226	1.60E+03	4.962E-11	2.798E-11	2.968E-11	3.955E-11	1.468E-10
Ra-228	5.76E+00	2.746E-08	2.016E-08	1.759E-08	1.811E-08	8.332E-08
Ac-227	2.18E+01	1.473E-07	9.812E-08	8.985E-08	6.784E-08	4.031E-07
Th-228	1.91E+00	6.101E-05	4.745E-05	1.131E-04	6.101E-05	2.826E-04
Th-229	7.30E+03	1.844E-07	1.173E-07	8.365E-08	1.027E-07	4.879E-07
Th-230	7.54E+04	6.032E-09	3.861E-09	4.693E-09	4.872E-09	1.946E-08
Th-232	1.40E+10	2.833E-08	2.126E-08	1.912E-08	1.865E-08	8.735E-08
Pa-231	3.28E+04	2.346E-07	1.732E-07	2.003E-07	1.160E-07	7.241E-07
U-232	7.00E+01	5.935E-05	4.616E-05	1.104E-04	5.938E-05	2.753E-04
U-233	1.59E+05	6.187E-05	4.649E-05	4.267E-05	3.728E-05	1.883E-04
U-234	2.46E+05	1.889E-05	1.314E-05	1.504E-05	1.416E-05	6.123E-05
U-235	7.04E+08	4.181E-09	3.956E-09	1.134E-09	1.025E-09	1.030E-08
U-236	2.34E+07	1.198E-06	8.926E-07	7.240E-07	7.175E-07	3.533E-06
U-238	4.47E+09	5.461E-06	4.102E-06	3.397E-06	3.445E-06	1.640E-05
Np-237	2.14E+06	2.874E-06	1.872E-06	1.551E-06	1.410E-06	7.706E-06
Pu-238	8.77E+01	6.901E-02	4.828E-02	6.671E-02	3.830E-02	2.223E-01

Table 7-16. (continued).

Isotope	Half-life (years)	09/15/01 Eight Buried Blocks from Core 1 (Ci for eight blocks)	09/15/01 Six Buried Blocks from Core 2 (Ci for six blocks)	09/15/01 Six Buried Blocks from Core 3 (Ci for six blocks)	09/15/01 Nine of the 16 OSCCs from Cores 1 and 2 (Ci per nine OSCCs)	Total Inventory for 20 Blocks and Nine OSCCs (Ci total)
Pu-239	2.41E+04	2.013E-02	1.512E-02	1.257E-02	9.665E-03	5.748E-02
Pu-240	6.56E+03	3.507E-02	2.624E-02	2.888E-02	2.972E-02	1.199E-01
Pu-241	1.44E+01	2.186E+00	2.031E+00	2.677E+00	1.273E+00	8.167E+00
Pu-242	3.75E+05	4.944E-04	3.609E-04	6.066E-04	5.936E-04	2.055E-03
Pu-244	8.00E+07	3.227E-10	3.000E-10	1.387E-09	1.736E-09	3.745E-09
Am-241	4.33E+02	2.258E-01	1.554E-01	1.052E-01	9.660E-02	5.829E-01
Am-243	7.37E+03	4.723E-03	3.499E-03	8.697E-03	8.174E-03	2.509E-02
Cm-243	2.91E+01	1.090E-03	8.508E-04	1.259E-03	6.415E-04	3.842E-03
Cm-244	1.81E+01	4.569E-01	4.492E-01	3.586E+00	2.577E+00	7.070E+00
Cm-245	8.50E+03	6.299E-05	5.323E-05	3.413E-04	2.583E-04	7.158E-04
Cm-246	4.76E+03	5.979E-05	6.118E-05	9.532E-04	9.941E-04	2.068E-03
Cm-247	1.56E+07	2.064E-10	2.502E-10	6.683E-09	6.186E-09	1.333E-08
Cm-248	3.48E+05	1.072E-09	1.668E-09	9.800E-08	1.128E-07	2.135E-07
Average transuranic concentration (nCi/g) =		547.20	511.44	460.93	377.54	479.82
Beryllium mass (g) =		651,360	488,520	488,520	489,881	2,118,281
Metal volume (m^3) =		0.352	0.264	0.264	0.265	1.145

CFR = *Code of Federal Regulations* OSCC = outer shim control cylinder

As another example, consider Block 011R from Core 3 (see Column 6 of Table 7-11). From Figure 7-3, or Table 7-1, Block 011R clearly was one of the six blocks disposed of from Core 3. Only Blocks 010R and 016L from Core 3 remain in the ATR canal. From Table 7-11, the ORIGEN2 calculated inventory for C-14 is listed as 2.497 Ci and the 10 CFR 61 (2002) sum-of-fractions rule is 3.415 (using all 10 CFR 61 [2002] isotopes). The Pu-239 inventory for Block 011R is shown as 1.910E-03 Ci. The average TRU concentration for Block 011R is shown as 340.98 nCi/g, and the average TRU concentration for all six blocks is listed in Table 7-11 as 377.05 nCi/g. All of these results were computed relative to the estimated disposal date of July 1, 1993. Similar results computed for the common decay date of September 15, 2001, for Core 3 are shown in Table 7-12.

The present analysis represents the best-estimate characterization that currently exists for the buried reflector blocks and OSCCs. However, some previous ORIGEN2 calculations were performed for ETR. The previous results were produced for three cases: a lower bound case, a best-estimate case, and an upper-bound scenario. Comparisons between the latest (new) best-estimate results and the previous (old) best-estimate results are shown in Tables 7-17 through 7-21. In general, the overall comparison of the new-to-old results is very good, with a few notable exceptions, namely, Nb-94, Eu-152, and Eu-154. The reason for the discrepancy in the calculated Nb-94 inventories is because of a recently revised estimate for the initial niobium (i.e., Nb-93 or elemental impurity concentration in the as-fabricated beryllium metal). The reason for the variation in the Eu-152 and Eu-154 results (e.g., see the new-to-old ratios in Table 7-17) is that the old analysis for the reflector blocks from Core 1 failed to model the initial europium impurity concentration in the beryllium metal. The error in the previous (old) calculations was eventually corrected in the subsequent calculations for the beryllium blocks from Cores 2, 3, and the OSCCs. In addition to producing Eu-152 and Eu-154 by nuclear fission, a substantial inventory of these radioisotopes also can be produced by neutron absorption in the stable forms of europium (namely, Eu-151 and Eu-153). Consequently, the ratios of the new-to-old values for Europium isotopes from Core 1 are very large (e.g., 301 and 25.4 in Table 7-17), but these ratios are much more reasonable for the reflector blocks from Cores 2, 3, and the OSCCs. Recent ANL-W measurements performed on the ATR beryllium samples have shown that the niobium impurity in the ATR beryllium is about 50 times higher than what was originally assumed to exist in the old analysis. Variations in the TRU radionuclide inventories between the new and old calculations are probably the result of the refined cross-section data that were generated and used in the new calculations. From Table 7-21, the average TRU concentration in the 20 reflector blocks and nine buried OSCCs was originally calculated at 869 nCi/g; however, the more recent analysis indicates this concentration to be approximately 300 nCi/g.

Table 7-17. Comparison of calculated radioisotope activities for the eight blocks disposed of from Core 1.

	Old Analysis Computed for 03/11/73	Old Analysis Computed for 03/11/73	Old Analysis Computed for 03/11/73	New Best Estimate Computed for 12/01/76	Old Analysis Decay Corrected to 12/01/76	12/01/76
Isotope	Eight Blocks Lower Bound (Ci)	Eight blocks Best Estimate (Ci)	Eight Blocks Upper Bound (Ci)	Eight Blocks Best Estimate (Ci)	Eight Blocks (Ci for eight blocks)	New to Old Comparison
H-3	9.54E+04	1.59E+05	2.23E+05	1.305E+05	1.290E+05	1.012
Be-10	5.62E-01	9.36E-01	1.31E+00	9.732E-01	9.360E-01	1.040
C-14	5.57E+00	9.28E+00	1.30E+01	7.811E+00	9.276E+00	0.842
Cl-36	3.92E-02	6.53E-02	9.14E-02	6.562E-02	6.530E-02	1.005
Co-60	7.44E+02	1.24E+03	1.74E+03	7.752E+02	7.597E+02	1.020
Ni-59	9.72E-02	1.62E-01	2.27E-01	1.652E-01	1.620E-01	1.020
Ni-63	1.75E+01	2.92E+01	4.09E+01	2.933E+01	2.846E+01	1.031
Sr-90	1.62E+00	2.70E+00	3.78E+00	2.519E+00	2.471E+00	1.020
Nb-94	1.97E-04	3.28E-04	4.59E-04	1.765E-02	3.280E-04	53.806

Table 7-17. (continued).

Isotope	Old Analysis Computed for 03/11/73	Old Analysis Computed for 03/11/73	Old Analysis Computed for 03/11/73	New Best Estimate Computed for 12/01/76	Old Analysis Decay Corrected to 12/01/76	12/01/76
	Eight Blocks Lower Bound (Ci)	Eight blocks Best Estimate (Ci)	Eight Blocks Upper Bound (Ci)	Eight Blocks Best Estimate (Ci)	Eight Blocks (Ci for eight blocks)	New to Old Comparison
Tc-99	5.81E-04	9.68E-04	1.36E-03	1.013E-03	9.680E-04	1.046
I-129	1.84E-06	3.07E-06	4.30E-06	7.436E-06	3.070E-06	2.422
Cs-137	4.50E+00	7.50E+00	1.05E+01	8.143E+00	6.885E+00	1.183
Eu-152	6.12E-04	1.02E-03	1.43E-03	2.535E-01	8.421E-04	301.010
Eu-154	4.85E-01	8.08E-01	1.13E+00	1.524E+01	5.982E-01	25.484
Pb-210	3.43E-11	5.72E-11	8.01E-11	1.742E-11	5.094E-11	0.342
Ra-226	2.24E-12	3.73E-12	5.22E-12	5.705E-12	3.724E-12	1.532
Ra-228	7.32E-09	1.22E-08	1.71E-08	1.705E-08	7.791E-09	2.188
Ac-227	3.46E-08	5.77E-08	8.08E-08	4.235E-08	5.124E-08	0.826
Th-228	7.08E-05	1.18E-04	1.65E-04	6.640E-05	3.059E-05	2.171
Th-229	1.60E-08	2.67E-08	3.74E-08	3.977E-08	2.669E-08	1.490
Th-230	1.90E-09	3.17E-09	4.44E-09	2.394E-09	3.170E-09	0.755
Th-232	1.79E-08	2.99E-08	4.19E-08	2.833E-08	2.990E-08	0.947
Pa-231	4.50E-07	7.50E-07	1.05E-06	2.347E-07	7.499E-07	0.313
U-232	1.47E-04	2.45E-04	3.43E-04	7.534E-05	2.361E-04	0.319
U-233	5.71E-05	9.52E-05	1.33E-04	6.188E-05	9.520E-05	0.650
U-234	5.04E-06	8.40E-06	1.18E-05	1.354E-05	8.400E-06	1.612
U-235	3.24E-09	5.40E-09	7.56E-09	3.689E-09	5.400E-09	0.683
U-236	9.36E-07	1.56E-06	2.18E-06	1.173E-06	1.560E-06	0.752
U-238	4.36E-06	7.26E-06	1.02E-05	5.461E-06	7.260E-06	0.752
Np-237	1.70E-06	2.84E-06	3.98E-06	1.571E-06	2.840E-06	0.553
Pu-238	8.10E-02	1.35E-01	1.89E-01	8.382E-02	1.311E-01	0.639
Pu-239	4.21E-02	7.02E-02	9.83E-02	2.014E-02	7.019E-02	0.287
Pu-240	3.24E-02	5.40E-02	7.56E-02	3.316E-02	5.398E-02	0.614
Pu-241	1.94E+01	3.23E+01	4.52E+01	7.210E+00	2.700E+01	0.267
Pu-242	2.16E-04	3.60E-04	5.04E-04	4.944E-04	3.600E-04	1.373
Pu-244	0	0	0	3.227E-10	0	—
Am-241	5.52E-02	9.20E-02	1.29E-01	6.486E-02	9.145E-02	0.709
Am-243	2.04E-03	3.40E-03	4.76E-03	4.734E-03	3.399E-03	1.393
Cm-243	0	0	0	1.992E-03	0	—
Cm-244	2.02E-01	3.37E-01	4.72E-01	1.180E+00	2.922E-01	4.038
Cm-245	0	0	0	6.312E-05	0	—
Cm-246	0	0	0	6.001E-05	0	—
Cm-247	0	0	0	2.064E-10	0	—
Cm-248	0	0	0	1.071E-09	0	—
TRU (nCi/g) =	326.94	544.96	763.28	321.36	538.06	

TRU = transuranic waste

Table 7-18. Comparison of calculated radioisotope activities for the six blocks disposed of from Core 2.

Isotope	Old Analysis Computed for 10/11/77 Six Blocks Lower Bound (Ci)	Old Analysis Computed for 10/11/77 Six Blocks Best Estimate (Ci)	Old Analysis Computed for 10/11/77 Six Blocks Upper Bound (Ci)	New Analysis Computed for 06/01/77 Six Blocks (Ci for six blocks)	Old Analysis Decay Corrected to 06/01/77 Six Blocks (Ci for six blocks)	06/01/77 New to Old Comparison
H-3	7.80E+04	1.30E+05	1.82E+05	1.228E+05	1.327E+05	0.926
Be-10	4.54E-01	7.56E-01	1.06E+00	7.264E-01	7.560E-01	0.961
C-14	4.46E+00	7.44E+00	1.04E+01	5.834E+00	7.440E+00	0.784
Cl-36	3.14E-02	5.23E-02	7.32E-02	4.889E-02	5.230E-02	0.935
Co-60	6.06E+02	1.01E+03	1.41E+03	1.013E+03	1.059E+03	0.956
Ni-59	7.62E-02	1.27E-01	1.78E-01	1.221E-01	1.270E-01	0.962
Ni-63	1.40E+01	2.33E+01	3.26E+01	2.252E+01	2.336E+01	0.964
Sr-90	1.32E+00	2.20E+00	3.08E+00	2.076E+00	2.219E+00	0.935
Nb-94	1.57E-04	2.62E-04	3.67E-04	1.314E-02	2.620E-04	50.137
Tc-99	4.72E-04	7.86E-04	1.10E-03	7.509E-04	7.860E-04	0.955
I-129	2.02E-06	3.36E-06	4.70E-06	5.529E-06	3.360E-06	1.645
Cs-137	4.57E-01	7.62E-01	1.07E+00	6.689E+00	7.684E-01	8.706
Eu-152	1.18E-01	1.97E-01	2.76E-01	3.189E-01	2.007E-01	1.589
Eu-154	8.88E+00	1.48E+01	2.07E+01	1.577E+01	1.524E+01	1.035
Pb-210	3.07E-11	5.12E-11	7.17E-11	1.513E-11	5.178E-11	0.292
Ra-226	1.61E-12	2.68E-12	3.75E-12	1.257E-12	2.680E-12	0.469
Ra-228	5.11E-09	8.52E-09	1.19E-08	7.744E-09	8.899E-09	0.870
Ac-227	2.46E-08	4.10E-08	5.74E-08	1.054E-08	4.147E-08	0.254
Th-228	5.58E-05	9.30E-05	1.30E-04	2.249E-05	1.060E-04	0.212
Th-229	1.16E-08	1.94E-08	2.72E-08	1.077E-08	1.940E-08	0.555
Th-230	1.47E-09	2.45E-09	3.43E-09	1.376E-09	2.450E-09	0.562
Th-232	1.34E-08	2.23E-08	3.12E-08	2.126E-08	2.230E-08	0.953
Pa-231	3.47E-07	5.78E-07	8.09E-07	1.732E-07	5.780E-07	0.300
U-232	1.21E-04	2.02E-04	2.83E-04	5.829E-05	2.027E-04	0.288
U-233	4.43E-05	7.38E-05	1.03E-04	4.524E-05	7.380E-05	0.613
U-234	3.89E-06	6.48E-06	9.07E-06	9.478E-06	6.480E-06	1.463
U-235	1.86E-09	3.10E-09	4.34E-09	3.595E-09	3.100E-09	1.160
U-236	6.96E-07	1.16E-06	1.62E-06	8.746E-07	1.160E-06	0.754
U-238	3.23E-06	5.38E-06	7.53E-06	4.102E-06	5.380E-06	0.762
Np-237	1.34E-06	2.24E-06	3.14E-06	1.108E-06	2.240E-06	0.495
Pu-238	6.36E-02	1.06E-01	1.48E-01	4.087E-02	1.063E-01	0.385
Pu-239	3.15E-02	5.25E-02	7.35E-02	1.512E-02	5.250E-02	0.288
Pu-240	2.45E-02	4.09E-02	5.73E-02	2.440E-02	4.090E-02	0.597
Pu-241	1.53E+01	2.55E+01	3.57E+01	6.540E+00	2.595E+01	0.252
Pu-242	1.85E-04	3.09E-04	4.33E-04	3.609E-04	3.090E-04	1.168
Pu-244	0	0	0	3.000E-10	0	NA
Am-241	4.03E-02	6.72E-02	9.41E-02	8.980E-03	6.724E-02	0.134
Am-243	1.88E-03	3.14E-03	4.40E-03	3.507E-03	3.140E-03	1.117
Cm-243	0	0	0	1.536E-03	0	NA
Cm-244	2.03E-01	3.38E-01	4.73E-01	1.138E+00	3.427E-01	3.322
Cm-245	0	0	0	5.335E-05	0	NA

Table 7-18. (continued).

Isotope	Old Analysis Computed for 10/11/77 Six Blocks Lower Bound (Ci)	Old Analysis Computed for 10/11/77 Six Blocks Best Estimate (Ci)	Old Analysis Computed for 10/11/77 Six Blocks Upper Bound (Ci)	New Analysis Computed for 06/01/77 Six Blocks (Ci for six blocks)	Old Analysis Decay Corrected to 06/01/77 Six Blocks (Ci for six blocks)	06/01/77 New to Old Comparison
Cm-246	0	0	0	6.139E-05	0	NA
Cm-247	0	0	0	2.502E-10	0	NA
Cm-248	0	0	0	1.660E-09	0	NA
TRU (nCi/g) =	331.54	552.79	773.23	194.26	553.50	

TRU = transuranic waste

Table 7-19. Comparison of calculated radioisotope activities for the six blocks disposed of from Core 3.

	Old Analysis Computed for 08/03/86	Old Analysis Computed for 08/03/86	Old Analysis Computed for 08/03/86	New Analysis Computed for 07/01/93	Old Analysis Decay Corrected to 07/01/93	07/01/93
Isotope	Six Blocks Lower Bound (Ci)	Six Blocks Best Estimate (Ci)	Six Blocks Upper Bound (Ci)	Six Blocks Best Estimate (Ci)	Six Blocks Best Estimate (Ci)	New to Old Comparison
H-3	1.61E+05	2.69E+05	3.77E+05	1.820E+05	1.824E+05	0.998
Be-10	8.76E-01	1.46E+00	2.04E+00	1.502E+00	1.460E+00	1.029
C-14	8.58E+00	1.43E+01	2.00E+01	1.196E+01	1.429E+01	0.837
Cl-36	5.76E-02	9.60E-02	1.34E-01	9.580E-02	9.600E-02	0.998
Co-60	8.04E+02	1.34E+03	1.88E+03	5.414E+02	5.401E+02	1.002
Ni-59	1.05E-01	1.75E-01	2.45E-01	1.747E-01	1.750E-01	0.998
Ni-63	2.36E+01	3.94E+01	5.52E+01	3.803E+01	3.756E+01	1.012
Sr-90	2.58E+00	4.30E+00	6.02E+00	3.242E+00	3.647E+00	0.889
Nb-94	2.78E-04	4.64E-04	6.50E-04	2.470E-02	4.639E-04	53.241
Tc-99	9.30E-04	1.55E-03	2.17E-03	1.359E-03	1.550E-03	0.877
I-129	3.18E-06	5.30E-06	7.42E-06	1.086E-05	5.300E-06	2.049
Cs-137	7.86E+00	1.31E+01	1.83E+01	1.107E+01	1.118E+01	0.990
Eu-152	6.60E-04	1.10E-03	1.54E-03	4.049E-03	7.710E-04	5.252
Eu-154	1.19E+00	1.99E+00	2.79E+00	4.656E+00	1.139E+00	4.086
Pb-210	1.38E-10	2.30E-10	3.22E-10	6.216E-11	1.855E-10	0.335
Ra-226	5.51E-12	9.18E-12	1.29E-11	1.498E-11	9.153E-12	1.636
Ra-228	7.56E-09	1.26E-08	1.76E-08	1.554E-08	5.486E-09	2.833
Ac-227	4.25E-08	7.08E-08	9.91E-08	5.684E-08	5.682E-08	1.000
Th-228	1.52E-04	2.54E-04	3.56E-04	1.183E-04	2.077E-05	5.695
Th-229	3.05E-08	5.08E-08	7.11E-08	5.062E-08	5.077E-08	0.997
Th-230	3.00E-09	5.00E-09	7.00E-09	3.640E-09	5.000E-09	0.728
Th-232	1.25E-08	2.09E-08	2.93E-08	1.912E-08	2.090E-08	0.915
Pa-231	4.00E-07	6.66E-07	9.32E-07	2.004E-07	6.659E-07	0.301
U-232	2.51E-04	4.19E-04	5.87E-04	1.194E-04	3.913E-04	0.305
U-233	5.11E-05	8.52E-05	1.19E-04	4.267E-05	8.520E-05	0.501
U-234	6.30E-06	1.05E-05	1.47E-05	1.344E-05	1.050E-05	1.280
U-235	4.82E-10	8.04E-10	1.13E-09	1.033E-09	8.040E-10	1.285
U-236	5.72E-07	9.54E-07	1.34E-06	7.175E-07	9.540E-07	0.752
U-238	2.71E-06	4.52E-06	6.33E-06	3.397E-06	4.520E-06	0.752
Np-237	1.92E-06	3.20E-06	4.48E-06	1.323E-06	3.200E-06	0.413
Pu-238	2.77E-01	4.61E-01	6.45E-01	7.117E-02	4.365E-01	0.163
Pu-239	2.75E-02	4.58E-02	6.41E-02	1.257E-02	4.579E-02	0.275
Pu-240	2.26E-02	3.76E-02	5.26E-02	2.524E-02	3.757E-02	0.672
Pu-241	1.68E+01	2.80E+01	3.92E+01	3.974E+00	2.008E+01	0.198
Pu-242	4.50E-04	7.50E-04	1.05E-03	6.066E-04	7.500E-04	0.809
Pu-244	0	0.00E+00	0	1.387E-09	0	—
Am-241	6.54E-02	1.09E-01	1.53E-01	6.307E-02	1.078E-01	0.585
Am-243	8.88E-03	1.48E-02	2.07E-02	8.703E-03	1.479E-02	0.588
Cm-243	0	0.00E+00	0	1.537E-03	0	—
Cm-244	2.14E+00	3.57E+00	5.00E+00	4.911E+00	2.740E+00	1.792
Cm-245	0	0.00E+00	0	3.415E-04	0	—
Cm-246	0	0.00E+00	0	9.543E-04	0	—

Table 7-19. (continued).

Isotope	Old Analysis Computed for 08/03/86 Six Blocks Lower Bound (Ci)	Old Analysis Computed for 08/03/86 Six Blocks Best Estimate (Ci)	Old Analysis Computed for 08/03/86 Six Blocks Upper Bound (Ci)	New Analysis Computed for 07/01/93 Six Blocks Best Estimate (Ci)	Old Analysis Decay Corrected to 07/01/93 Six Blocks Best Estimate (Ci)	07/01/93 New to Old Comparison
Cm-247	0	0.00E+00	0	6.683E-09	0	—
Cm-248	0	0.00E+00	0	9.785E-08	0	—
TRU (nCi/g) =	822.55	1,369.35	1,916.92	377.05	1,316.66	

TRU = transuranic waste

Table 7-20. Comparison of calculated radioisotope activities for the nine outer shim control cylinders disposed of from Cores 1 and 2.

	Old Analysis Computed for 02/09/78	Old Analysis Computed for 02/09/78	Old Analysis Computed for 02/09/78	New Analysis Computed for 09/01/87	Old Analysis Decay Corrected to 09/01/87	09/01/87
Isotope	Nine OSCCs Lower Bound (Ci)	Nine OSCCs Best Estimate (Ci)	Nine OSCCs Upper Bound (Ci)	Nine OSCCs Best Estimate (Ci)	Nine OSCCs Best Estimate (Ci)	New to Old Comparison
H-3	1.47E+05	2.45E+05	4.90E+05	8.615E+04	1.432E+05	0.602
Be-10	7.98E-01	1.33E+00	2.66E+00	2.010E+00	1.330E+00	1.512
C-14	7.80E+00	1.30E+01	2.60E+01	1.593E+01	1.298E+01	1.227
Cl-36	5.24E-02	8.74E-02	1.75E-01	9.663E-02	8.740E-02	1.106
Co-60	7.32E+02	1.22E+03	2.44E+03	4.151E+02	3.471E+02	1.196
Ni-59	9.54E-02	1.59E-01	3.18E-01	1.939E-01	1.590E-01	1.219
Ni-63	2.15E+01	3.58E+01	7.16E+01	4.575E+01	3.351E+01	1.365
Sr-90	2.35E+00	3.91E+00	7.82E+00	3.000E+00	3.114E+00	0.963
Nb-94	2.54E-04	4.23E-04	8.46E-04	2.802E-02	4.229E-04	66.259
Tc-99	8.46E-04	1.41E-03	2.82E-03	1.351E-03	1.410E-03	0.958
I-129	2.90E-06	4.83E-06	9.66E-06	1.089E-05	4.830E-06	2.255
Cs-137	7.14E+00	1.19E+01	2.38E+01	1.026E+01	9.554E+00	1.074
Eu-152	5.99E-04	9.99E-04	2.00E-03	2.976E-03	6.111E-04	4.871
Eu-154	1.09E+00	1.81E+00	3.62E+00	3.595E+00	8.370E-01	4.295
Pb-210	1.26E-10	2.10E-10	4.20E-10	3.485E-11	1.560E-10	0.223
Ra-226	5.01E-12	8.35E-12	1.67E-11	1.531E-11	8.315E-12	1.841
Ra-228	6.90E-09	1.15E-08	2.30E-08	1.633E-08	3.641E-09	4.485
Ac-227	3.86E-08	6.44E-08	1.29E-07	4.067E-08	4.750E-08	0.856
Th-228	1.39E-04	2.31E-04	4.62E-04	6.896E-05	7.238E-06	9.528
Th-229	2.77E-08	4.62E-08	9.24E-08	5.332E-08	4.616E-08	1.155
Th-230	2.73E-09	4.55E-09	9.10E-09	3.183E-09	4.550E-09	0.700
Th-232	1.15E-08	1.91E-08	3.82E-08	1.865E-08	1.910E-08	0.977
Pa-231	3.64E-07	6.06E-07	1.21E-06	1.161E-07	6.059E-07	0.192
U-232	2.29E-04	3.82E-04	7.64E-04	6.797E-05	3.475E-04	0.196
U-233	4.65E-05	7.75E-05	1.55E-04	3.729E-05	7.750E-05	0.481
U-234	5.74E-06	9.56E-06	1.91E-05	1.254E-05	9.560E-06	1.312
U-235	4.39E-10	7.32E-10	1.46E-09	8.911E-10	7.320E-10	1.217
U-236	5.21E-07	8.68E-07	1.74E-06	7.062E-07	8.680E-07	0.814
U-238	2.47E-06	4.12E-06	8.24E-06	3.445E-06	4.120E-06	0.836
Np-237	1.75E-06	2.91E-06	5.82E-06	1.049E-06	2.910E-06	0.361
Pu-238	2.52E-01	4.20E-01	8.40E-01	4.278E-02	3.895E-01	0.110
Pu-239	2.50E-02	4.17E-02	8.34E-02	9.665E-03	4.169E-02	0.232
Pu-240	2.05E-02	3.42E-02	6.84E-02	2.468E-02	3.417E-02	0.722
Pu-241	1.53E+01	2.55E+01	5.10E+01	2.503E+00	1.610E+01	0.156
Pu-242	4.10E-04	6.83E-04	1.37E-03	5.935E-04	6.830E-04	0.869
Pu-244	0	0	0	1.736E-09	0.0	—
Am-241	5.93E-02	9.88E-02	1.98E-01	5.743E-02	9.730E-02	0.590
Am-243	8.10E-03	1.35E-02	2.70E-02	8.185E-03	1.349E-02	0.607
Cm-243	0	0	0	9.025E-04	0.0	—
Cm-244	1.95E+00	3.25E+00	6.50E+00	4.411E+00	2.254E+00	1.957
Cm-245	0	0	0	2.586E-04	0.0	—

Table 7-20. (continued).

Isotope	Old Analysis Computed for 02/09/78 Nine OSCCs Lower Bound (Ci)	Old Analysis Computed for 02/09/78 Nine OSCCs Best Estimate (Ci)	Old Analysis Computed for 02/09/78 Nine OSCCs Upper Bound (Ci)	New Analysis Computed for 09/01/87 Nine OSCCs Best Estimate (Ci)	Old Analysis Decay Corrected to 09/01/87 Nine OSCCs Best Estimate (Ci)	09/01/87 New to Old Comparison
Cm-246	0	0	0	9.961E-04	0.0	—
Cm-247	0	0	0	6.186E-09	0.0	—
Cm-248	0	0	0	1.127E-07	0.0	—
TRU (nCi/g) =	745.72	1,242.93	2,486.68	297.01	1,177.39	

OSCC = outer shim control cylinder TRU = transuranic waste

Table 7-21. Overall comparison of calculated radioisotope activities for the 20 blocks plus nine outer shim control cylinders computed at various disposal dates.

Isotope	New Analysis Computed at the Disposal Dates 20 blocks + Nine OSCCs Best Estimate (Ci)	Old Analysis Decay Corrected to Disposal Dates 20 blocks + Nine OSCCs Best Estimate (Ci)	New to Old Comparison
H-3	5.215E+05	5.872E+05	0.888
Be-10	5.212E+00	4.482E+00	1.163
C-14	4.154E+01	4.399E+01	0.944
Cl-36	3.069E-01	3.010E-01	1.020
Co-60	2.745E+03	2.706E+03	1.014
Ni-59	6.559E-01	6.230E-01	1.053
Ni-63	1.356E+02	1.229E+02	1.104
Sr-90	1.084E+01	1.145E+01	0.946
Nb-94	8.350E-02	1.477E-03	56.543
Tc-99	4.475E-03	4.714E-03	0.949
I-129	3.472E-05	1.656E-05	2.097
Cs-137	3.617E+01	2.838E+01	1.274
Eu-152	5.794E-01	2.029E-01	2.855
Eu-154	3.926E+01	1.781E+01	2.204
Pb-210	1.296E-10	4.443E-10	0.292
Ra-226	3.725E-11	2.387E-11	1.560
Ra-228	5.666E-08	2.582E-08	2.195
Ac-227	1.504E-07	1.970E-07	0.763
Th-228	2.761E-04	1.646E-04	1.678
Th-229	1.545E-07	1.430E-07	1.080
Th-230	1.059E-08	1.517E-08	0.698
Th-232	8.735E-08	9.220E-08	0.947
Pa-231	7.244E-07	2.600E-06	0.279
U-232	3.210E-04	1.178E-03	0.273
U-233	1.871E-04	3.317E-04	0.564
U-234	4.900E-05	3.494E-05	1.403
U-235	9.207E-09	1.004E-08	0.917
U-236	3.472E-06	4.542E-06	0.764
U-238	1.640E-05	2.128E-05	0.771
Np-237	5.051E-06	1.119E-05	0.451
Pu-238	2.387E-01	1.063E+00	0.224
Pu-239	5.750E-02	2.102E-01	0.274
Pu-240	1.075E-01	1.666E-01	0.645
Pu-241	2.023E+01	8.912E+01	0.227
Pu-242	2.055E-03	2.102E-03	0.978
Pu-244	3.745E-09	0	—
Am-241	1.943E-01	3.638E-01	0.534
Am-243	2.513E-02	3.482E-02	0.722

Table 7-21. (continued).

Isotope	New Analysis Computed at the Disposal Dates 20 blocks + Nine OSCCs Best Estimate (Ci)	Old Analysis Decay Corrected to Disposal Dates 20 blocks + Nine OSCCs Best Estimate (Ci)	New to Old Comparison
Cm-243	5.968E-03	0	—
Cm-244	1.164E+01	5.630E+00	2.068
Cm-245	7.166E-04	0	—
Cm-246	2.072E-03	0	—
Cm-247	1.333E-08	0	—
Cm-248	2.133E-07	0	—
TRU (nCi/g) =	299.26	869.04	

OSCC = outer shim control cylinder TRU = transuranic waste

7.9 Analysis of the Materials Test Reactor and Engineering Test Reactor Beryllium Reflectors

A number of similarities can be noted between the ETR and MTR beryllium reflectors and the reflector in the ATR:

- All cores are approximately the same size. The ATR core is a little taller than the other two, but about the same nominal lateral dimension as the ETR. The MTR core was smaller and more elongated. The ATR fuel is in a serpentine pattern while the ETR fuel is essentially a 10×10 element square grid with fuel in some locations replaced by test loops. The MTR fuel was a 5×9 array of nominally 7.6-cm (3-in.) square fuel elements 40×73 cm (15.7×28.8 in.). Additional details of the MTR and ETR can be found in the *Directory of Nuclear Reactors* (IAEA 1959; IAEA 1964).

- All beryllium reflectors are nominally the same height as the fuel elements.

- The ATR and ETR reflectors are in close proximity to the fuel, though the ETR configuration is nominally square while the ATR configuration provides a transition between the serpentine core and the cylindrical housing. The outer part of the MTR reflector was more removed from the fuel, as shown in Figure 3-1.

- All reflectors (counting the OSCCs in the ATR) have approximately the same effective thickness from the fuel to the surroundings, though the ETR is slightly thinner than the other two.

- None of the three reactors uses a top or bottom reflector, other than the water coolant.

- Both ATR and ETR reactors appear to have operated at about half the rated power. The MTR reactor operated at its rated power for most of its life. However, because of a relatively low operating time, the average power was less than one-third of the rated power over the last half of its life.

- All of the beryllium reflectors appear to be made of very similar material, which would imply similar impurities.

- Neutron energy spectra are probably quite similar for each of the reactors, though the spectrum is probably more thermalized in the MTR reflector than in the ATR and ETR reflectors.

- The overall vertical spatial distribution of flux in all three reactors is probably quite similar.

The MTR first went critical on March 31, 1952. It first reached its designed operating power of 30 MW_{th} on May 22, 1952. It operated at nominally the 30-MW_{th} power level for about 40 months, until September 1955. Then, it was found that the reactor could operate satisfactorily at 40 MW_{th}, and it operated at that level (when it was in operation) until July 3, 1969, when it was shut down. At that time, the initial beryllium reflector was replaced, and the enriched uranium fuel was removed. In late 1969, a second beryllium reflector and a new plutonium fuel core were installed. The second beryllium reflector still resides inside the shutdown reactor. The MTR operated using the replacement reflector from December 1969 until April 1970 and for about 3 days in August 1970 using a plutonium fuel (Rolfe and Wills 1984, Chapter 2). The total amount of energy that was generated in the MTR from May 22, 1952, until July 3, 1969, (i.e., Cycle 1 through 295) was 177,887 MWd (Ford et al. 1969). A slightly larger value of 179,323 MWd is reported by Rolfe and Wills (1984); however, Rolfe and Wills report this value being generated through about Cycle 305 (until mid 1969). For the current analysis, a value of 177,887 MWd was assumed to be uniformly generated during the entire 6,303 days of MTR operation, a period of time that used the first beryllium reflector. In other words, an average reactor power of 28.22 MW (= 177,887 MWd/6,303 days) is assumed for each of the 6,303 days of operation of MTR. In addition to the energy generation, the total neutron flux (i.e., fast+thermal) per MW of reactor power and the total beryllium mass were determined in order to perform an ORIGEN2 calculation. A beryllium mass of about 2,608 kg (5,750 lb) is reported by Rolfe and Wills (1984); however, this value appears to be too high (e.g., the beryllium would have to occupy the entire MTR core and reflector volumes). A more reasonable mass number can be estimated based on the physical dimensions of the reflector as reported in Volume II of the *Directory of Nuclear Reactors* (IAEA 1959). Calculations of the MTR reflector volume (taking into consideration void spaces for beam ports) indicate that the reflector metal volume is between 934,000 and 1,174,000 cm^3. The average metal volume is ~1,054,000 cm^3. Using a nominal beryllium density of 1.85 g/cm^3, an average beryllium mass of ~2,000,000 g can be determined to one significant decimal place. The estimated uncertainty associated with the calculated MTR beryllium mass number is ±14%.

The fast and thermal neutron fluxes for each of the major reflector components are reported in Volume II of the *Directory of Nuclear Reactors* (IAEA 1959) for the MTR at a nominal reactor power of 40 MW. An average value of the fast and thermal neutron fluxes can be determined by averaging the individual reflector components. The total flux is then the sum of the fast and thermal components. The best-estimate total neutron flux for the MTR reflector (at 40 MW), computed to one significant decimal place, is 1×10^{14} n/cm^2/second. Since the average MTR power was previously determined to be 28.22 MW, the time-averaged (steady-state) neutron flux is 7.056×10^{13} n/cm^2/second.

In addition to the neutron flux, the beryllium mass, and the average reactor power, the elemental composition of the beryllium reflector material (both major and trace elements) was estimated based on chemical assay data. The result of this analysis is displayed in Table 7-22. The information shown in Table 7-22 applies to both the MTR and ETR reflectors. These data assume that both beryllium reflectors were made from KBI beryllium; however, trace element information from Brush Wellman assay data was used whenever KBI data were not available. In general, it is not known which company actually supplied the beryllium for the initial MTR and ETR core loadings although the second reflector for ETR was made by Brush Wellman using S-200 E-grade material (see drawing number 400883).

Using the above (steady-state) neutron flux (i.e., 7.056×10^{13} n/cm^2/second) computed at the beryllium reflector, the total irradiation time (6,303 days from May 22, 1952, until July 3, 1969), and the estimated beryllium mass (2,000,000 g), an ORIGEN2 computer code model was produced for the MTR reflector. The detailed ORIGEN2 input deck for MTR is shown in Appendix E. The results of the ORIGEN2 calculation for selected radionuclides are listed in Table 7-23. Note that the calculated C-14 inventory for the MTR beryllium reflector at the time of disposal of this material at the SDA is 29.2 Ci. The calculated C-14 inventory for MTR also is shown in Table 1-1.

The ETR first went critical in October 1957 with full power being achieved in April 1958 (Kaiser et al.1982, p. 11; IAEA 1964). The reflector was replaced in March 1970 (Kaiser et al. 1982, p. 35). In May 1973, the mission of the ETR changed from thermal-hydraulic testing to pursuit of fast breeder reactor issues. During the entirety of its lifetime, the first reflector in the ETR experienced the same kind of testing operations. The length of time that the ETR was operated with the first beryllium reflector installed in the reactor (e.g., Core 1) was about 4,520 days (e.g., October 15, 1957, to March 1, 1970). The total energy generation that occurred during this time is estimated to be 380,000 MWd and is based on a value extrapolation of 374,498 MWd reported for January 11, 1970, by E. H. Smith et al. (1970). An axially averaged total neutron flux of 4.93×10^{14} n/cm^2/second (at 175 MW or 2.817×10^{14} n/cm^2/second per MW), computed at the ETR beryllium reflector, was estimated from the neutron flux data reported in Volume V of the *Directory of Nuclear Reactors* (IAEA 1964). For example, the thermal flux was determined to be the average of the two values mentioned for the 1.3-in. diameter beryllium access holes: 2×10^{14} and 6×10^{14} n/cm^2/second. Hence, ϕ_{th}=4.0x10^{14} n/cm^2/second (at 175 MW). The fast neutron flux (ϕ_{fast}) was determined by estimating the ratio of the fast to thermal flux (ϕ_{fast} / ϕ_{th} = ~2/3) and then multiplying the thermal flux by this ratio. Hence, the total peak flux within the ETR beryllium reflector at 175 MW is: $\phi_{peak} = \phi_{th} + \phi_{fast} = 4 \times 10^{14} + 2.7 \times 10^{14} = 6.7 \times 10^{14}$ n/cm^2/second. The axial peak power to average core power ratio for ETR is ~1.36. Therefore, the average axial total neutron flux at the ETR beryllium reflector is computed as follows: $\phi_{total} = \phi_{peak} /1.36 = 6.7 \times 10^{14}/1.36 = 4.93 \times 10^{14}$ n/cm^2/second (calculated at 175 MW of ETR power).

Table 7-22. Principal and trace elements within the Materials Test Reactor beryllium reflector. The same concentrations are assumed to apply to the Engineering Test Reactor beryllium reflectors.

Element Symbol	Element Name	Number	Atomic Weight	Average KBI Beryllium Concentration (ppm by wt)	Estimated Inventory for a 2,000-kg MTR Beryllium Reflector Mass (g)	Actual Modeled ORIGEN2 Input Data Mass (g)	Ratio Estimated/ Modeled
H	Hydrogen	1	1.0079		0.000	0.000	
He	Helium	2	4.0026		0.000	0.000	
Li	Lithium	3	6.9410	1.000	2.000	2.000	1.000E+00
Be	Beryllium	4	9.0122	980,667.835	1,961,335.670	1,961,000.000	1.000E+00
B	Boron	5	10.8110	1.917	3.833	3.833	1.000E+00
C	Carbon	6	12.0110	745.000	1,490.000	1,490.000	1.000E+00
N	Nitrogen	7	14.0067	205.400	410.800	410.800	1.000E+00
O	Oxygen	8	15.9994	12,618.667	25,237.333	25,240.000	9.999E-01
F	Fluorine	9	18.9984	69.167	138.333	138.300	1.000E+00
Ne	Neon	10	20.1797	1,425.000	2,850.000	2,850.000	1.000E+00
Na	Sodium	11	22.9898	0.874	1.749	1.749	9.998E-01
Mg	Magnesium	12	24.3050	45.000	90.000	90.000	1.000E+00
Al	Aluminum	13	26.9815	355.833	711.667	711.700	1.000E+00
Si	Silcon	14	28.0855	364.167	728.333	728.300	1.000E+00
P	Phosphorus	15	30.9738	50.000	100.000	100.000	1.000E+00
S	Sulfur	16	32.0660	7.500	15.000	15.000	1.000E+00
Cl	Chlorine	17	35.4527	50.000	100.000	100.000	1.000E+00
Ar	Argon	18	39.9480	6.370	12.740	12.740	1.000E+00
K	Potassium	19	39.0983	13.070	26.140	26.140	1.000E+00
Ca	Calcium	20	40.0780	200.000	400.000	400.000	1.000E+00
Sc	Scandium	21	44.9559	2.300	4.600	4.600	1.000E+00
Ti	Titanium	22	47.8800	61.667	123.333	123.300	1.000E+00
V	Vanadium	23	50.9415	3.423	6.847	6.847	1.000E+00
Cr	Chromiun	24	51.9961	92.500	185.000	185.000	1.000E+00
Mn	Manganese	25	54.9381	56.667	113.333	113.300	1.000E+00
Fe	Iron	26	55.8470	1,499.167	2,998.333	2,998.000	1.000E+00
Co	Cobalt	27	58.9332	12.000	24.000	24.000	1.000E+00
Ni	Nickel	28	58.6900	225.833	451.667	451.700	9.999E-01
Cu	Copper	29	63.5460	87.500	175.000	175.000	1.000E+00
Zn	Zinc	30	65.3900	13.000	26.000	26.000	1.000E+00
Ga	Gallium	31	69.7230	0.859	1.719	1.719	9.998E-01
Ge	Germanium	32	72.6100	5.000	10.000	10.000	1.000E+00
As	Arsenic	33	74.9216	1.782	3.564	3.564	1.000E+00
Se	Selenium	34	78.9600	2.383	4.767	4.767	9.999E-01
Br	Bromine	35	79.9040	52.000	104.000	104.000	1.000E+00
Kr	Krypton	36	83.8000	85.167	170.333	170.300	1.000E+00
Rb	Rubidium	37	85.4678	7.767	15.533	15.530	1.000E+00
Sr	Strontium	38	87.6200	6.000	12.000	12.000	1.000E+00
Y	Yttrium	39	88.9059	1.000	2.000	2.000	1.000E+00
Zr	Zirconium	40	91.2240	38.214	76.429	76.430	1.000E+00
Nb	Niobium	41	92.9064	11.700	23.400	23.400	1.000E+00
Mo	Molybdenum	42	95.9400	10.000	20.000	20.000	1.000E+00
Tc	Technetium	43	98.9062		0.000	0.000	

Table 7-22. (continued).

Element Symbol	Element Name	Number	Atomic Weight	Average KBI Beryllium Concentration (ppm by wt)	Estimated Inventory for a 2,000-kg MTR Beryllium Reflector Mass (g)	Actual Modeled ORIGEN2 Input Data Mass (g)	Ratio Estimated/ Modeled
Ru	Ruthenium	44	101.0700	5.000	10.000	10.000	1.000E+00
Rh	Rhodium	45	102.9055	0.994	1.987	1.987	1.000E+00
Pd	Palladium	46	106.4200	5.000	10.000	10.000	1.000E+00
Ag	Silver	47	107.8682	2.167	4.333	4.333	1.000E+00
Cd	Cadmium	48	112.4110	1.000	2.000	2.000	1.000E+00
In	Indium	49	114.8200	0.069	0.137	0.137	9.998E-01
Sn	Tin	50	118.7100	3.000	6.000	6.000	1.000E+00
Sb	Antimony	51	121.7500	0.241	0.481	0.481	9.999E-01
Te	Tellurium	52	127.6000	47.467	94.933	94.930	1.000E+00
I	Iodine	53	126.9045	10.000	20.000	20.000	1.000E+00
Xe	Xenon	54	131.2900	537.333	1,074.667	1,075.000	9.997E-01
Cs	Cesium	55	132.9054	0.201	0.403	0.403	9.999E-01
Ba	Barium	56	137.3270	6.000	12.000	12.000	1.000E+00
La	Lanthanum	57	138.9055	1.000	2.000	2.000	1.000E+00
Ce	Cerium	58	140.1150	1.000	2.000	2.000	1.000E+00
Pr	Praseodymium	59	140.9077	1.000	2.000	2.000	1.000E+00
Nd	Neodymium	60	144.2400	5.000	10.000	10.000	1.000E+00
Pm	Promethium	61	144.9145		0.000	0.000	
Sm	Samarium	62	150.3600	0.500	1.000	1.000	1.000E+00
Eu	Europium	63	151.9650	0.500	1.000	1.000	1.000E+00
Gd	Gadolinium	64	157.2500	0.200	0.400	0.400	1.000E+00
Tb	Terbium	65	158.9253	1.000	2.000	2.000	1.000E+00
Dy	Dysprosium	66	162.5000	0.200	0.400	0.400	1.000E+00
Ho	Holmium	67	164.9303	1.000	2.000	2.000	1.000E+00
Er	Erbium	68	167.2600	0.500	1.000	1.000	1.000E+00
Tm	Thulium	69	168.9342	0.500	1.000	1.000	1.000E+00
Yb	Ytterbium	70	173.0400	0.200	0.400	0.400	1.000E+00
Lu	Lutetium	71	174.9670	0.667	1.333	1.333	1.000E+00
Hf	Hafnium	72	178.4900	0.423	0.847	0.847	1.000E+00
Ta	Tantalum	73	180.9479	0.433	0.866	0.866	1.000E+00
W	Tungsten	74	183.8500	76.214	152.428	152.400	1.000E+00
Re	Rhenium	75	186.2070	0.644	1.288	1.288	1.000E+00
Os	Osmium	76	190.2000	0.637	1.274	1.274	1.000E+00
Ir	Iridium	77	192.2200	0.005	0.010	0.010	1.000E+00
Pt	Platinum	78	195.0800	101.867	203.734	203.700	1.000E+00
Au	Gold	79	196.9665	24.800	49.600	49.600	1.000E+00
Hg	Mercury	80	200.5900	4.073	8.146	8.146	1.000E+00
Tl	Thallium	81	204.3833	25.000	50.000	50.000	1.000E+00
Pb	Lead	82	207.2000	1.000	2.000	2.000	1.000E+00
Bi	Bismuth	83	208.9804		0.000	0.000	
Po	Polonium	84			0.000	0.000	
At	Astatine	85			0.000	0.000	
Rn	Radon	86			0.000	0.000	
Fr	Francium	87			0.000	0.000	

Table 7-22. (continued).

Element Symbol	Element Name	Number	Atomic Weight	Average KBI Beryllium Concentration (ppm by wt)	Estimated Inventory for a 2,000-kg MTR Beryllium Reflector Mass (g)	Actual Modeled ORIGEN2 Input Data Mass (g)	Ratio Estimated/ Modeled
Ra	Radium	88			0.000	0.000	
Ac	Actinium	89			0.000	0.000	
Th	Thorium	90	232.0381	0.438	0.876	0.876	1.000E+00
Pa	Protactinium	91			0.000	0.000	
U	Uranium	92	238.0289	30.000	60.000	60.000	1.000E+00
Np	Neptunium	93			0.000	0.000	
Pu	Plutonium	94			0.000	0.000	
Am	Americium	95			0.000	0.000	
			Totals =	1,000,000.000	2,000,000.000	1,999,666.830	

KBI = Kawecki Berylco Industries MTR = Materials Test Reactor
ORIGEN2 = Oak Ridge Isotope GENeration and Depletion Code Version 2

Table 7-23. Oak Ridge Isotope GENeration and Depletion Code Version 2 calculated inventory for Materials Test Reactor beryllium blocks from Core 1. Irradiated from March 31, 1952, to July 1, 1969 (U=30 ppm).

Isotope	Half-Life (years)	MTR Be Inventory on 07/01/69, EOI Date (Ci)	MTR Be Inventory on 07/02/77, Estimated Disposal Date (Ci)	MTR Be Inventory on 09/15/01, Common Decay Date (Ci)
H-3	1.23E+01	1.449E+06	9.248E+05	2.377E+05
Be-10	1.23E+01	3.644E+00	3.644E+00	3.644E+00
C-14	1.23E+01	2.925E+01	2.922E+01	2.913E+01
Cl-36	1.23E+01	3.467E-01	3.466E-01	3.466E-01
Co-60	1.23E+01	2.816E+03	9.834E+02	4.074E+01
Ni-59	1.23E+01	5.544E-01	5.543E-01	5.542E-01
Ni-63	1.23E+01	1.049E+02	9.880E+01	8.233E+01
Sr-90	1.23E+01	9.269E-02	7.663E-02	4.307E-02
Nb-94	1.23E+01	7.737E-02	7.735E-02	7.729E-02
Tc-99	1.23E+01	2.916E-01	2.919E-01	2.918E-01
I-129	1.23E+01	9.718E-02	9.729E-02	9.729E-02
Cs-137	1.23E+01	5.015E+00	4.169E+00	2.383E+00
Eu-152	1.23E+01	2.714E-02	1.806E-02	5.259E-03
Eu-154	1.23E+01	2.818E+01	1.479E+01	2.103E+00
10 CFR 61 (2002) Sum-of-fractions rule for:				
C14+Ni59+Nb94+Tc99+I129 =		1.912	1.913	1.912
C14+Ni59+Nb94+Tc99+I129+Pu241 =		1.962	1.947	1.922
Ni63+Sr90+Cs137 =		0.015	0.014	0.011
Pb-210	2.23E+01	4.720E-12	3.912E-12	3.545E-12
Ra-226	1.60E+03	3.776E-11	9.384E-11	4.071E-10
Ra-228	5.76E+00	2.945E-10	3.263E-10	3.490E-10
Ac-227	2.18E+01	3.657E-09	7.327E-09	1.412E-08
Th-228	1.91E+00	6.969E-07	9.117E-07	7.357E-07
Th-229	7.30E+03	9.880E-07	1.737E-06	4.000E-06
Th-230	7.54E+04	6.790E-07	9.263E-07	2.131E-06
Th-232	1.40E+10	7.491E-01	7.491E-01	7.491E-01
Pa-231	3.28E+04	3.058E-05	3.060E-05	3.058E-05
U-232	7.00E+01	3.735E-05	3.461E-05	2.742E-05
U-233	1.59E+05	2.110E-02	2.182E-02	2.182E-02
U-234	2.46E+05	9.272E-03	1.289E-02	2.254E-02
U-235	7.04E+08	3.570E-03	3.847E-03	4.687E-03
U-236	2.34E+07	5.009E-02	5.049E-02	5.187E-02
U-238	4.47E+09	4.284E+01	4.284E+01	4.284E+01
Np-237	2.14E+06	1.043E-02	1.169E-02	2.092E-02
Pu-238	8.77E+01	5.155E-02	5.638E-02	4.661E-02
Pu-239	2.41E+04	1.217E+00	1.225E+00	1.224E+00
Pu-240	6.56E+03	4.488E-01	4.997E-01	5.848E-01
Pu-241	1.44E+01	3.512E-01	2.390E-01	7.454E-02
Pu-242	3.75E+05	6.636E-01	6.637E-01	6.636E-01
Pu-244	8.00E+07	9.686E-05	9.686E-05	9.686E-05
Am-241	4.33E+02	3.716E-02	1.481E-01	3.032E-01

Table 7-23. (continued).

Isotope	Half-Life (years)	MTR Be Inventory on 07/01/69, EOI Date (Ci)	MTR Be Inventory on 07/02/77, Estimated Disposal Date (Ci)	MTR Be Inventory on 09/15/01, Common Decay Date (Ci)
Am-243	7.37E+03	1.570E-01	1.569E-01	1.565E-01
Cm-243	2.91E+01	2.858E-04	2.353E-04	1.306E-04
Cm-244	1.81E+01	1.978E-01	1.456E-01	5.767E-02
Cm-245	8.50E+03	7.351E-03	7.346E-03	7.332E-03
Cm-246	4.76E+03	5.513E-03	5.507E-03	5.487E-03
Cm-247	1.56E+07	1.195E-04	1.195E-04	1.195E-04
Cm-248	3.48E+05	2.013E-05	2.021E-05	2.021E-05
	All Actinides =	4.684E+01	4.684E+01	4.684E+01
	TRU concentration (nCi/g) =	1299.46	1387.40	1506.41
	Beryllium mass (g) =	2,000,000.00	2,000,000.00	2,000,000.00
	Metal volume (m^3) =	1.0811	1.0811	1.0811

file=MTR3.wb1

CFR = *Code of Federal Regulations* EOI = end of irradiation MTR = Materials Test Reactor
TRU = transuranic waste

Now, a total energy generation of 374,498 MWd over 4,520 days produces an average thermal reactor power of 84.07 MW, or an equivalent (steady-state) total neutron flux of 2.368×10^{14} n/cm^2/second (e.g., $4.93 \times 10^{14} \times 84.07/175$) at the ETR beryllium reflector during the entire 4,520 days of operation for Core 1. The ORIGEN2 input deck modeling the ETR reflector is shown in Appendix F. The results of the ORIGEN2 calculation for selected radionuclides are listed in Table 7-24. Note that the calculated C-14 inventory for the ETR beryllium reflector at the time of disposal of this material in the SDA is 21.7 Ci. The calculated C-14 inventory for ETR also is shown in Table 1-1.

Table 7-24. Oak Ridge Isotope GENeration and Depletion Code Version 2 calculated inventory for Engineering Test Reactor beryllium blocks from Core 1 irradiated from October 15, 1957, to March 1, 1970 (U = 30 ppm).

Isotope	Half-Life (years)	ETR Be Inventory on 03/01/70, EOI Date (Ci)	ETR Be Inventory on 04/30/70, Estimated Disposal Date (Ci)	ETR Be Inventory on 09/15/01, Common Decay Date (Ci)
H-3	1.23E+01	1.222E+06	1.210E+06	2.080E+05
Be-10	1.23E+01	2.734E+00	2.734E+00	2.734E+00
C-14	1.23E+01	2.170E+01	2.170E+01	2.162E+01
Cl-36	1.23E+01	2.291E-01	2.291E-01	2.291E-01
Co-60	1.23E+01	2.037E+03	1.993E+03	3.214E+01
Ni-59	1.23E+01	2.344E-01	2.344E-01	2.343E-01
Ni-63	1.23E+01	6.505E+01	6.497E+01	5.129E+01
Sr-90	1.23E+01	8.468E+00	8.435E+00	3.997E+00
Nb-94	1.23E+01	4.824E-02	4.824E-02	4.819E-02
Tc-99	1.23E+01	2.468E-03	2.471E-03	2.471E-03
I-129	1.23E+01	2.498E-05	2.500E-05	2.501E-05
Cs-137	1.23E+01	3.009E+01	2.998E+01	1.452E+01
Eu-152	1.23E+01	1.403E-03	1.391E-03	2.810E-04
Eu-154	1.23E+01	5.218E+00	5.149E+00	4.106E-01
10 CFR 61 (2002) Sum-of-fractions rule for:				
	C14+Ni59+Nb94+Tc99+I129 =	1.526	1.526	1.522
	C14+Ni59+Nb94+Tc99+I129+Pu241 =	5.007	4.980	2.285
	Ni63+Sr90+Cs137 =	0.051	0.050	0.033
Pb-210	2.23E+01	6.235E-10	6.268E-10	2.804E-10
Ra-226	1.60E+03	1.075E-11	1.114E-11	1.250E-10
Ra-228	5.76E+00	1.518E-08	1.527E-08	2.037E-08
Ac-227	2.18E+01	3.414E-08	3.603E-08	2.643E-07
Th-228	1.91E+00	2.288E-04	2.391E-04	3.093E-04
Th-229	7.30E+03	5.562E-08	5.642E-08	2.181E-07
Th-230	7.54E+04	5.418E-09	5.444E-09	1.184E-08
Th-232	1.40E+10	2.058E-08	2.058E-08	2.058E-08
Pa-231	3.28E+04	3.968E-07	3.976E-07	3.973E-07
U-232	7.00E+01	4.074E-04	4.072E-04	3.011E-04
U-233	1.59E+05	4.900E-05	5.347E-05	5.468E-05
U-234	2.46E+05	1.812E-05	1.816E-05	2.677E-05
U-235	7.04E+08	1.640E-09	1.643E-09	2.106E-09
U-236	2.34E+07	6.062E-07	6.063E-07	6.476E-07
U-238	4.47E+09	2.827E-06	2.827E-06	2.827E-06
Np-237	2.14E+06	1.609E-06	1.627E-06	2.942E-06
Pu-238	8.77E+01	7.905E-02	8.585E-02	8.533E-02
Pu-239	2.41E+04	1.469E-02	1.500E-02	1.500E-02
Pu-240	6.56E+03	2.050E-02	2.086E-02	6.018E-02
Pu-241	1.44E+01	7.604E+00	7.544E+00	1.667E+00
Pu-242	3.75E+05	8.644E-04	8.644E-04	8.649E-04
Pu-244	8.00E+07	5.141E-09	5.141E-09	5.141E-09
Am-241	4.33E+02	8.115E-03	1.011E-02	1.995E-01
Am-243	7.37E+03	1.352E-02	1.353E-02	1.349E-02

Table 7-24. (continued).

Isotope	Half-Life (years)	ETR Be Inventory on 03/01/70, EOI Date (Ci)	ETR Be Inventory on 04/30/70, Estimated Disposal Date (Ci)	ETR Be Inventory on 09/15/01, Common Decay Date (Ci)
Cm-243	2.91E+01	3.272E-03	3.259E-03	1.520E-03
Cm-244	1.81E+01	2.051E+01	2.038E+01	6.133E+00
Cm-245	8.50E+03	1.806E-03	1.806E-03	1.802E-03
Cm-246	4.76E+03	9.004E-03	9.004E-03	8.964E-03
Cm-247	1.56E+07	1.154E-07	1.154E-07	1.154E-07
Cm-248	3.48E+05	2.852E-06	2.855E-06	2.938E-06
	All Actinides =	2.648E+03	3.533E+01	8.204E+00
	TRU concentration (nCi/g) =	241.71	256.87	619.64
	Beryllium mass (g) =	624,000.00	624,000.00	624,000.00
	Metal volume (m^3) =	0.3373	0.3373	0.3373

CFR = *Code of Federal Regulations* EOI = end of irradiation ETR = Engineering Test Reactor
TRU = transuranic waste

8. CONCLUSIONS AND RECOMMENDATIONS

8.1 Conclusions

This report applies new characterization data (measured and modeled) developed for the future disposal of the ATR beryllium to inventory estimates of irradiated beryllium disposed of in the SDA from the MTR, ETR, and ATR. Though a number of radioisotopes were modeled and documented in this study, the analysis focused on C-14 and several TRU isotopes identified as potential risk drivers for OU 7-13/14 (Becker et al. 1998). The conclusions derived from this study follow:

- The C-14 inventory in the buried MTR, ETR, and ATR beryllium is approximately 50 Ci, a reduction of approximately 31 Ci from previously reported data. The majority of the C-14 reduction (26 Ci) was from a reduction in the estimates of disposed-of beryllium from the MTR and the ETR. The estimated TRU inventories in buried beryllium are small compared to the total TRU inventories in the SDA.

- Before this study, it was unknown whether uranium was present in sufficient concentrations in the ATR beryllium to produce a waste with a significant TRU inventory. This study not only verifies that TRU concentrations are present in the ATR beryllium, but that these concentrations exceed 100 nCi/g for TRU. Also, this study concludes that the beryllium reflectors from the first core loadings of the MTR and ETR (material that was disposed of in the SDA) exceed the 100 -nCi/g limit for TRU.

- Approximately 3.6 Ci of TRU isotopes are attributable to the disposal of MTR, ETR, and ATR beryllium. The majority of the curie increase (approximately 2.6 Ci) was from the estimate for the MTR.

- Computer modeling for characterization of the ATR beryllium blocks and OSCCs was validated by comparing model concentrations to actual measured concentrations for several isotopes at two sample point locations on Block 010R. This study is the first case in which significant measured data have been obtained on the ATR beryllium core components and then compared against computer code results. The results of these comparisons have shown that the best-estimate computer code results are generally within a factor of 2 for most measured data. The data presented in this report represent the best-estimate characterization currently available for approximately 40 radionuclides considered in this analysis.

- The calculated Pu-239 and TRU values using both the segmented model and the single-block model (computed at Site 1 and Site 2 cells) are in very good agreement (usually within a factor of 2 or better) and are in agreement with the sample assay measurements taken from Site 1 and Site 2. This information provides validation of the computer models and the basis for the segmented and single-block computer models to accurately determine the total block inventory of TRU isotopes and other radionuclides of interest.

- Based on the segmented three-dimensional model calculation, more than 96% of the beryllium block mass exceeds 100 nCi/g. In addition, nearly 50% of the block mass exceeds 400 nCi/g.

- The calculated TRU total inventory for Block 010R was 277.08 nCi/g using the segmented model and associated detailed analysis. The corresponding single-block model calculated a more conservative TRU total block average concentration of 491.23 nCi/g, as reported in Tables 6-4 or 7-12. (Note: in Table 7-12, the 010R inventory is the same as that shown for Block 015L.)

- The TRU concentration is a dynamic quantity and can be accurately determined from computer analysis. The primary variables that influence the TRU inventory are irradiation time, initial uranium inventory, neutron flux, and decay time. During irradiation, the TRU inventory tends to build up until a maximum value is reached before the TRU isotopes begin to burn out and decrease the total TRU concentration. However, following irradiation, the TRU isotopes significantly increase in concentration because of the beta decay of the non-TRU isotope Pu-241 into the TRU isotope Am-241.

- The segmented model provides insight into the three-dimensional distribution of important isotopes within a typical ATR beryllium block. This distribution includes TRU isotopes, C-14, and H-3. The segmented three-dimensional model also is a powerful tool for determining alternative or representative sampling locations for future sampling.

- The elemental assay data presented in this report represent the best-estimate chemical impurity information that is known for beryllium reflector material used at the INEEL and in the industry. In addition, best-estimate reactor operating conditions were assumed in the calculations for the MTR, ETR, and ATR beryllium components.

- Before this investigation, it was not know how many Core 2 blocks had been disposed of. The current investigation indicates that two of the Core 2 blocks still reside in the ATR canal and that six Core 2 blocks were disposed of on or about June 1, 1977, in the SDA. Though it was originally known that nine OSCCs had been disposed of in the SDA, whether all of these shim cylinders came from the Cores 1 and 2 irradiation was not known. This study has confirmed that the OSCCs came from Cores 1 and 2, but which core positions these OSCCs occupied still are unknown. The serial numbers for the buried OSCCs and many of the reflector block serial numbers are not known.

8.2 Recommendations

Although the MTR and ETR characterization data in this report apply specifically to beryllium disposed of from these reactors, with slight revision the data also could be applied to beryllium reflector materials and other core components remaining in the ETR and MTR reactors to support future waste disposal for facility D&D&D. The *Characterization of the Engineering Test Reactor Facility* (Kaiser et al. 1982) and *Characterization of the Materials Testing Reactor* (Rolfe and Wills 1984) reports should be revised to reflect information provided in this report.

All beryllium reflector material currently stored in the ATR canal and beryllium material to be generated in the future should be modeled to estimate the total radiological inventory to support future waste path planning. The modeling should be expanded also to estimate the radiological inventory that will result from continued operation of the ATRC reactor.

Finally, some remedial efforts should be considered in order to minimize the release of C-14 from the beryllium metal disposed of in the SDA.

9. REFERENCES

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